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The reproductive biology, early life history, and growth of white suckers, *Catostomus commersoni,* and longnose suckers, *C. catostomus,* in the Willow Creek-Chain Lakes system, Alberta.

by

Bryan Douglas Walton

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

DEPARTMENT OF ZOOLOGY

EDMONTON, ALBERTA
FALL, 1979

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "The reproductive biology, early life history, and growth of white suckers, *Catostomus commersoni*, and longnose suckers, *C. catostomus*, in the Willow Creek-Chain Lakes system, Alberta" submitted by Bryan Douglas Walton in partial fulfilment of the requirements for the degree of Master of Science.

J.S. Nelson

Supervisor

R. Macnab

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Date May 23/79

ABSTRACT

The reproductive biology, early life history, and growth of white suckers, *Catostomus commersoni*, and longnose suckers, *C. catostomus*, in the Willow Creek-Chain Lakes system, Alberta, were studied from April 1975 to January 1977. Willow Creek, the largest of two tributaries to Chain Lakes reservoir, provides good spawning habitat for white suckers and longnose suckers. The spring spawning migration of white and longnose suckers began when stream temperature reached 10°C; thereafter, the rate of movement was influenced, to a degree, by discharge. Virtually all upstream and downstream movement occurred at night. Seasonal and diel movement were not associated with turbidity. During the peak of the spawning migration in May there were an estimated 11,390 white suckers and 773 longnose suckers in the lower 11 km of the stream. Tagged white suckers ascended the creek over 10.3 km; however, there was little evidence of population interchange between lower and upper reaches of the creek. Upstream migrant white suckers from upper and lower reaches of the creek, in May, were not greatly different in size or age. Longnose suckers were not captured in upper reaches of the creek.

Spawning activity increased after upstream movement subsided in late May. Incubation times for white suckers and longnose suckers were 15 days ($\bar{x}$ temp. 10°C) and 14 days ($\bar{x}$ temp. 12.2°C) respectively. Larvae emerged from the gravel about 11 days after hatching and commenced drifting downstream. Larval drift occurred mainly at night and most fry (larvae) were captured near surface. Increased buoyancy, caused by initial inflation of the swim bladder, may have brought more fry into the upper part of the water column. Drifting fry had a mean length of 12.02 mm. Embryological development of white and longnose suckers was examined; however, no morphological differences were noted between species.

Compared to other populations, white suckers were relatively slow growing, longnose suckers were not. After sexual maturity was reached in both species, females were larger than males of the same age. Cross sectioned pectoral fin rays were reliable for age determination and back calculation. The maximum ages of white and longnose suckers were XII and VIII respectively. Fish older than VI were rare in the sample. Differences in growth rates between the two species may be related to diet and competition for food.

White and longnose suckers exhibited annual reproductive cycles which were reflected by seasonal changes in weight and histological appearance of the gonads. Spermatogenesis was virtually complete by November, but oogenesis lagged behind. Ovaries gained most of their weight by mid-winter and continued to develop gradually up to spawning time. Microscopically, ovaries from white suckers were similar to those of longnose suckers. One major difference was detected in testes of white suckers and longnose suckers: spermatozoa were oval in white suckers and spherical in longnose suckers. Fecundity of both species was relatively low, a fact that may be related to suboptimal habitat and over crowding in Chain Lakes reservoir.

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INTRODUCTION

White suckers, *Catostomus commersoni*, and longnose suckers, *C. catostomus*, are sympatric throughout most of northern North America (Nelson 1973). The broad ecological tolerance of both species enables them to inhabit a wide range of aquatic habitats including: rivers and streams (Bond 1972; Tripp and McCart 1974); small shallow lakes (Geen *et al.* 1966); and large deep lakes (Coble 1967; Harris 1962). White and longnose suckers also adapt very well to reservoir habitats (Bassett 1957; Hayes 1956; Nelson 1965). Their success in impoundments may, however, degrade sport fisheries (Lagler 1956), either by competing with desirable species or by their predominance in the creel. An increase in the sucker population in Chain Lakes reservoir and Willow Creek, Alberta, and a concomitant decline in the sport fishery, during the nine year post impoundment period prompted this study. Emphasis was placed on examining the reproductive biology and early life history of the suckers in Willow Creek. The objectives of this study are as follows:

(i) to provide life history data on white and longnose suckers that will be useful in future management programs

(ii) to increase the knowledge of the biology of white suckers and longnose suckers, especially the latter, in Alberta

(iii) to examine certain hitherto unknown or poorly understood aspects of the ecology of white and longnose suckers

(iv) to discuss the findings of the study as they relate to past studies on catostomid biology.

This thesis is presented in four chapters. Each chapter deals with a particular aspect of the ecology of white and longnose suckers. Chapter I examines migratory patterns and vital statistics of migrant suckers. Chapter II deals with spawning behavior, incubation, and downstream movements of fry. Chapter III pertains to age and growth. Chapter IV documents annual gonad development and fecundity. The results of all four chapters are addressed in a general discussion.

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CHAPTER I Vital statistics and migratory patterns of white suckers, *Catostomus commersoni*, and longnose suckers, *C. catostomus*, in Willow Creek, Alberta

ABSTRACT

Seasonal, diel, and instream movements of white suckers, *Catostomus commersoni*, and longnose suckers, *C. catostomus*, were monitored at Willow Creek, Alberta, using two-way fish traps and electrofishing gear. The spring spawning migration of both species commenced when the stream temperature exceeded 10°C. Upstream movements and some downstream movements in the lower reaches of the creek were positively correlated with discharge. While seasonal movement was associated with discharge, diel movement was influenced by light conditions. Over a 24 hour period, virtually all upstream and downstream movement occurred at night. Turbidity (concentration of suspended sediment) was not related to seasonal or diel movement.

There was little mixing between suckers in lower and upper reaches of the creek over one summer. Fish tagged at the lower fence (600 m above the mouth) were not recaptured at the upper fence (16.4 km above the mouth); only

two fish tagged at the upper fence were recaptured at the lower fence. White suckers captured moving upstream at the upper fence were only about 5% as numerous as those captured moving upstream at the lower fence. Longnose suckers were not captured at the upper fence. Most of the white suckers tagged at the lower fence were recaptured, by electroshocking, within 3.0 km upstream of the release point (lower fence). Tagged white suckers and longnose suckers were recaptured upstream a maximum distance of 10.3 km and 1.1 km respectively. During the height of the spawning migration in May, there was an estimated 11,390 white suckers and 773 longnose suckers in the lower 11 km of Willow Creek.

Most suckers entered the creek to spawn for the first time at ages V and VI. Females were usually larger than males of the same age. Upstream migrant white suckers from the lower and upper reaches of the creek were not significantly different in size or age; although, small sub-adult (immature) fish migrating downstream at the upper fence were part of a stream resident population. An absence of longnose sucker in the upper reaches and the numerical dominance of white suckers throughout the stream is thought to be related to the habitat in Chain Lakes reservoir being better suited to white suckers.

V

INTRODUCTION

Geen *et al.* (1966) found that variation in stream temperature was an important factor governing seasonal and diel movement of white and longnose suckers. Increases in stream temperature rather than fluctuations in discharge seemed to initiate and regulate seasonal upstream movement. Others have also found that rising water temperature enhances upstream movement of suckers (Bailey 1969; Bond 1972; Brown and Graham 1953; Raney and Webster 1942; Rawson and Elsey 1948). With the exception of Geen (1958) and Geen *et al.* (1966), few researchers have examined, in detail, other environmental factors that may influence seasonal and diel movement.

Most publications on the migration of white and longnose suckers have dealt with seasonal timing, population dynamics, and diel movement. Little is known of the instream movements of either species, specifically, distance and rate of upstream movement. There is some evidence to suggest that early migrants move further upstream and stay longer than later migrants (Geen *et al.* 1966; Raney and Webster 1942). Furthermore, size, sex, and gonad maturity of migrant fish may have a bearing on their instream movements.

This chapter reports on environmental factors associated with seasonal and diel movements of white and longnose suckers in Willow Creek, Alberta. Instream migration and vital statistics of the migrants are also discussed.

STUDY AREA

The study area is approximately 90 km south of Calgary in the central east slope of the Rocky Mountains of Alberta (Fig. 1). Field investigations were carried out on 18.2 km of Willow Creek above Chain Lakes Reservoir (lat. 50° 11' 47" N, long. 114° 12' 46" W). During peak flow periods water drains from the reservoir over a spillway at the south end of the impoundment. This spillway is a partial barrier to fish moving out of the reservoir and likely blocks upstream movement into the reservoir.

Willow Creek has a drainage area of 162.7 km^2 and a gradient of 8.37. The average width of the creek is 10 m and mid summer depths range from a few centimeters to over 2.5 m in deeper pools. Over a 9 year period (1965-1973) mean annual discharge was 1.14 cubic meters per second (cms): mean monthly discharge was highest in June (4.58 cms) and lowest in January (0.12 cms) (Water Survey of Canada 1974). The creek is ice covered from about November to April.

Willow Creek travels through uncultivated rangeland. Riparian vegetation consists of aspen (*Populus* sp.), white spruce (*Picea glauca*), lodgepole pine (*Pinus contorta*), willow (*Salix* sp.), alder (*Alnus* sp.), and grasses.

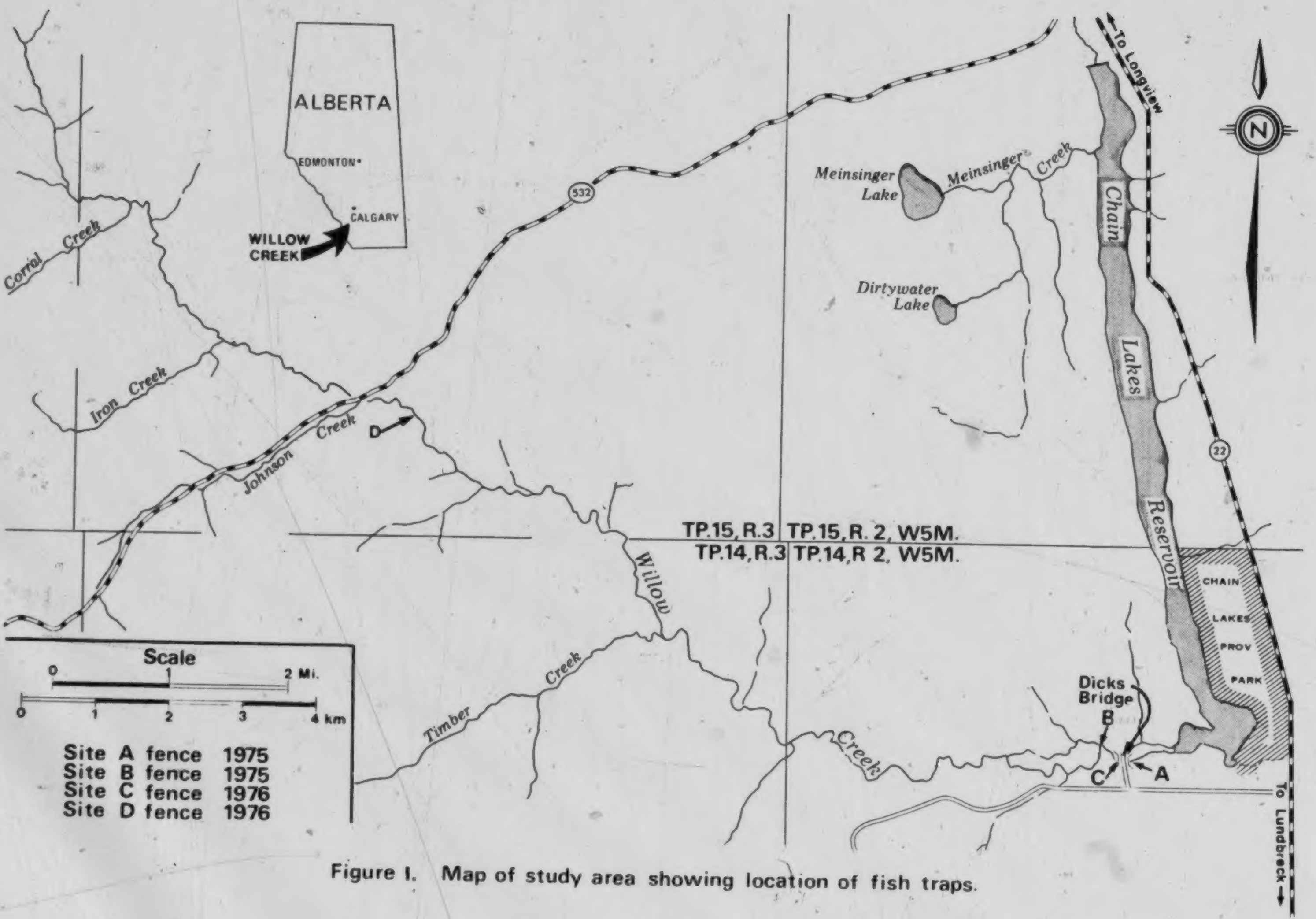
ALBERTA
EDMONTON
CALGARY
WILLOW CREEK
Corral Creek
Iron Creek
Johnson Creek
D
532
Meinsinger Lake
Meinsinger Creek
Dirtywater Lake
Chain Lakes Reservoir
To Longview
22
N
TP.15, R.3 TP.15, R. 2, W5M.
TP.14, R.3 TP.14, R 2, W5M.
CHAIN LAKES PROV PARK
Willow Creek
Timber Creek
Dicks Bridge
B
C
A
To Lundbreck
Scale
0 1 2 Mi.
0 1 2 3 4 km
Site A fence 1975
Site B fence 1975
Site C fence 1976
Site D fence 1976

Figure I. Map of study area showing location of fish traps.

Fish species known to occur in the reservoir and or the creek are: white suckers, longnose suckers, mountain suckers (*Catostomus platyrhynchus*), longnose dace (*Rhinichthys cataractae*), lake chub (*Couesius plumbeus*), fathead minnow (*Pimephales promelas*), rainbow trout (*Salmo gairdneri*), cutthroat trout (*Salmo clarki*), brown trout (*Salmo trutta*), brook trout (*Salvelinus fontinalis*), bull trout (*Salvelinus confluentus*), mountain whitefish (*Prosopium williamsoni*), and brook stickleback (*Culaea inconstans*).

MATERIALS AND METHODS

Field studies were carried out from 24 April to 30 July 1975, and from 21 April to 5 August 1976. Movements of fish were monitored at four locations (Fig. 1). Upstream and downstream traps were installed in all locations except at Site B. In 1975 the Site A fence was situated 550 m upstream from the mouth of Willow Creek, and the Site B fence was installed at the mouth of a side channel of Willow Creek 50 m upstream from Site A. In 1976 the Site C (lower) fence was installed 600 m upstream from the mouth of Willow Creek and the Site D (upper) fence was installed 16.4 km upstream from the mouth of Willow Creek. All fences were designed from the fish barrier described by Shetter (1938).

Panels from each fence were removed during peak flood periods to reduce erosion of the substrate at the fence and to prevent damage to the structure. No attempt was made to enumerate fish moving in the stream when fences were inoperative. Traps were tended daily and fish were generally counted each morning. Fish not taken for sampling were released in the direction they were travelling upon capture.

Fish were tagged in 1976 with floy tags coded to indicate date and location of capture. Tags were inserted on the left side just below the dorsal fin and anchored in the dorsal pterygiophores. At each site, some fish were fin clipped by removing the distal half of a particular fin. At Site C, upstream migrants had the right pectoral fin clipped, and downstream migrants had the left pectoral fin clipped. Pelvic fins were clipped in a similar fashion at Site D; right fins were clipped in upstream migrants and left fins were clipped on downstream migrants.

Fish were sampled in a routine manner. Fork length, total length, and standard length (mm), and weight, to the nearest 0.1 g, were recorded. The right pectoral fin and several scales from the right side above the lateral line, below the dorsal fin, were removed for age determination. Each fish was coded as immature (nonspawner), mature (green), ripe, or spent.

Stream temperatures were recorded with Peabody Ryan 30 day strip chart recorders. Reference temperatures were taken daily, with a pocket thermometer, at each fence. Discharge and suspended sediment data were obtained from Inland Waters Station No. 05AB028 at Dicks Bridge (Fig. 1). Discharge at Site D was calculated on three occasions by the float method (Hynes 1972), and the data were compared with the discharge readings at Site C. Seasonal data were then extrapolated for Site D from the readings at the lower station.

Diel trap checks were conducted on eight occasions. Traps were checked at four hour intervals (i.e., 1000 hrs, 1400 hrs, etc.): all fish were counted and disposed of. All fish were removed from the trap boxes prior to the start of each check and the traps were then checked 4 hrs later when each experiment began.

The stream was staked off in 100 m sections from the mouth upstream for 18.2 km. Fish were collected above Site C with a Smith-Root MK VII backpack electroshocker. Shocking was conducted from 31 May to 2 June, and on 9 June 1976. Shocking started from section 8 and continued upstream to section 110 (11.0 km). Shocking was done over 2.9, 3.0, and 3.1 km zones of the creek: 11 or 12 sections in each zone were sampled. Fish were identified, counted, and examined for tags, and then released.

Complete seasonal movement data were analyzed by partial correlation (Steel and Torrie 1960). Incomplete capture data from days when fences were inoperative were not used in the analyses. The number of fish captured each day was correlated with maximum temperature, concentration of suspended sediment, and discharge data from the previous day. Unpaired students t-test was used to compare lengths and weights, and chi^2 (goodness of fit) was used to present sex ratios (Sokal and Rohlf 1969). Population estimates were based on the Lincon Index or Petersen method (Cormack 1969); confidence limits were calculated as explained by Ricker (1975).

RESULTS

Seasonal Movement, 1975 - Sites A and B

Limited seasonal movement data were obtained as a result of severe floods. Seasonal movement of white suckers (Fig. 2) and longnose suckers (Fig. 3) was not significantly correlated with variation in discharge, concentration of suspended sediment or maximum stream temperature. Application of statistical analyses were restricted by the small data set.

Initial upstream movement was related to water temperature. Suckers were not observed in the lower 600 m of the creek until water temperature reached 10°C on 15 May. Prior to this time, when the Site A fence was operational on 29 April and 6 May, no fish were captured. Snow and low air temperatures in early May kept water temperatures down and probably delayed the onset of the spawning migration. Upstream captures peaked during the fourth week in May and gradually subsided in June.

An abrupt drop in water levels in June resulted in a major exodus of spawners from the side channel. The Site B fence was dismantled on 5 June to allow descending

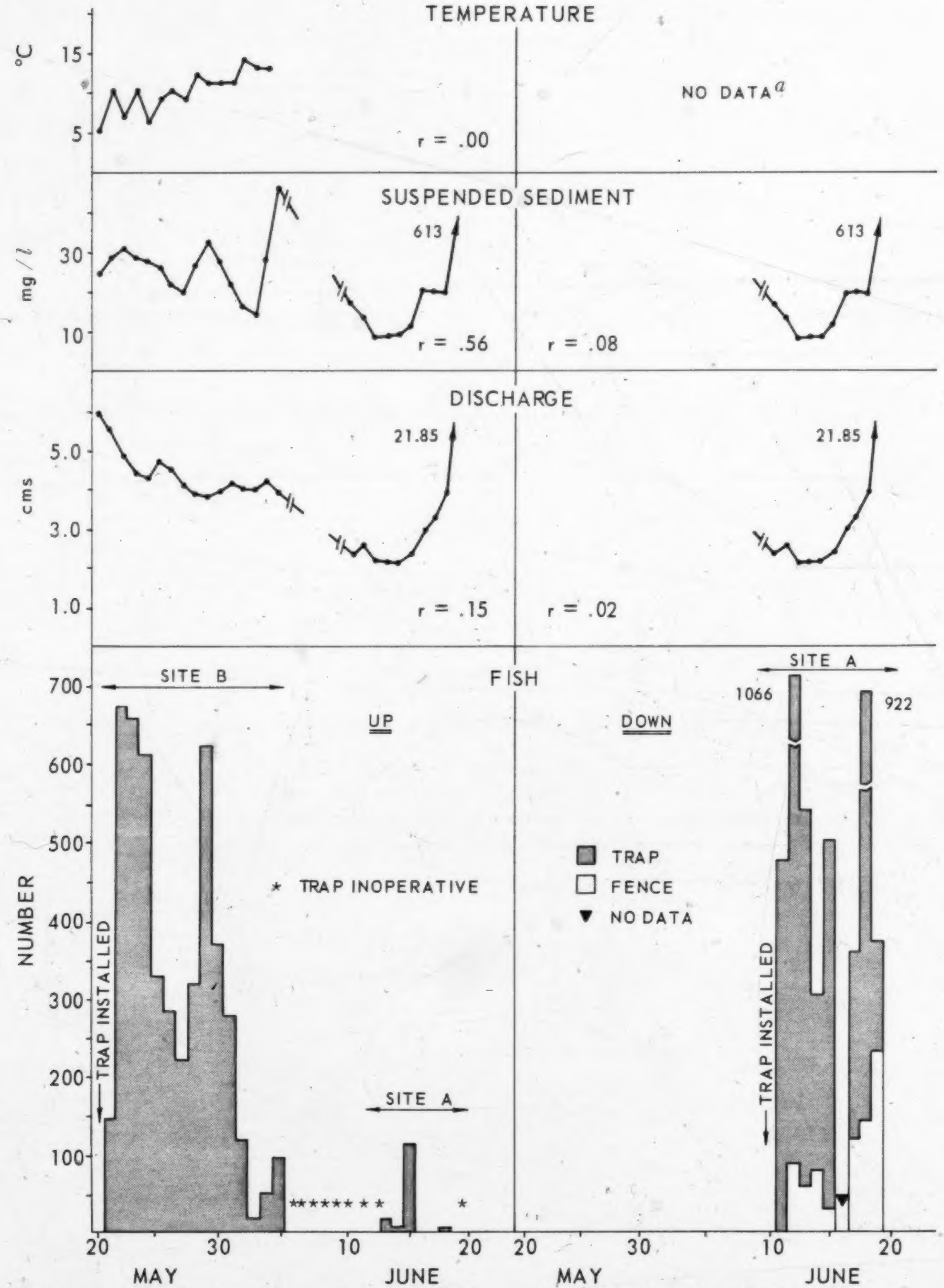

Figure 2. Seasonal movement of white suckers at sites A and B, 1975, and daily values for discharge, concentration of suspended sediment, and maximum stream temperature. Partial correlation coefficients (r) for each variable versus movement are in respective boxes. [a]Thermograph lost in flood.

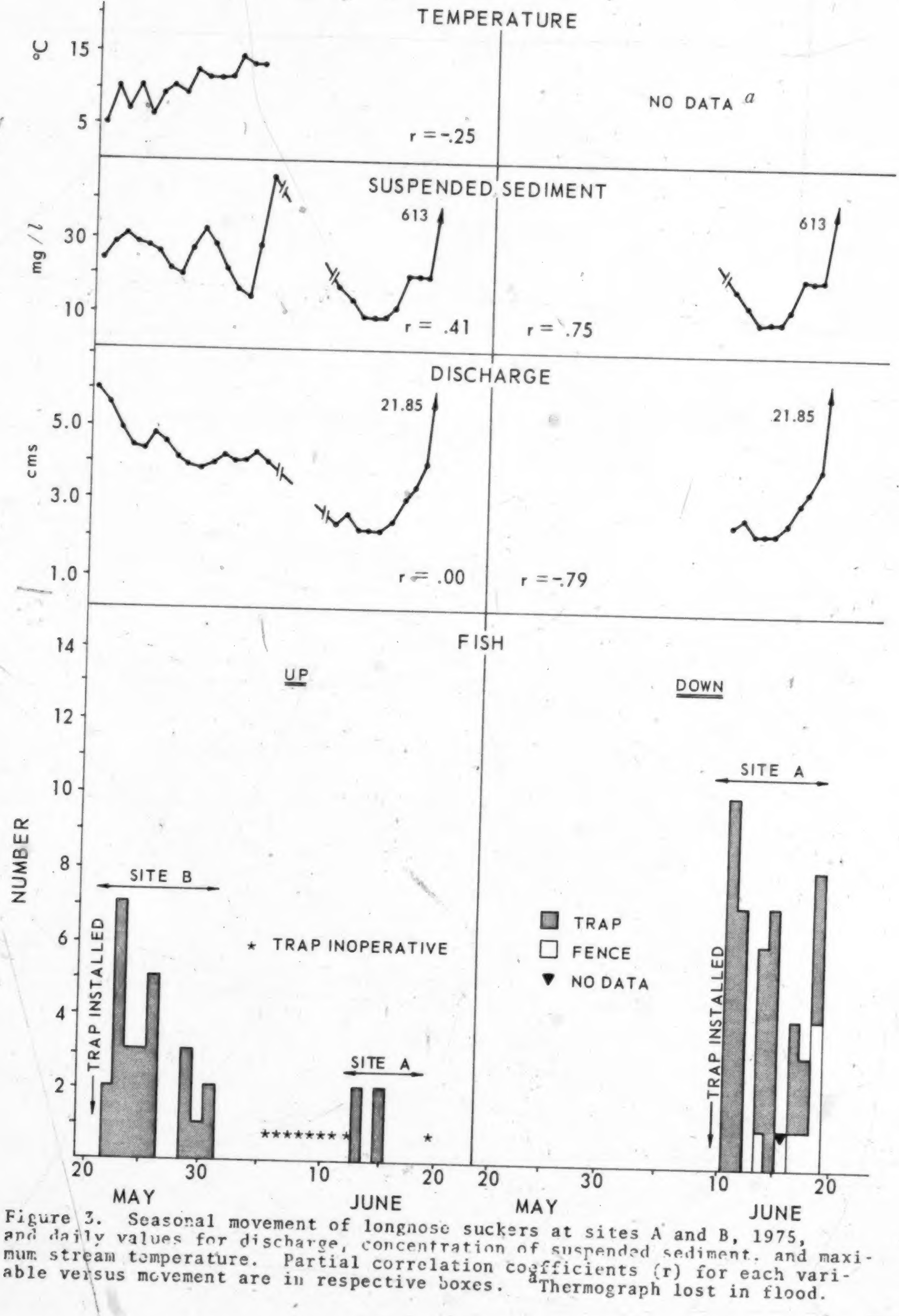

Figure 3. Seasonal movement of longnose suckers at sites A and B, 1975, and daily values for discharge, concentration of suspended sediment, and maximum stream temperature. Partial correlation coefficients (r) for each variable versus movement are in respective boxes. [a]Thermograph lost in flood.

fish to enter the main stream. Downstream captures at Site A peaked around the middle of June (Figs. 2 and 3). There was a steady downstream migration during the time the fence was in operation.

Upstream traps (Sites A and B) were functional for 23 days and the downstream trap (Site A) was functional for 8 days. During this time 4799 white suckers and 26 longnose suckers were captured ascending the side channel, and 180 white suckers and 4 longnose suckers were captured moving up the main channel. The downstream trap at Site A caught 3786 white suckers and 38 longnose suckers. The ratio of white suckers to longnose suckers captured during the summer (all traps) was 129:1.

Seasonal Movement, 1976 - Sites C and D

Upstream

The pattern of upstream movement of white suckers was similar to that of longnose suckers at the lower fence (Site C) (Figs. 4 and 5). An initial migration of spawners in May was followed by a run of spent and immature fish in late June. Upstream migration of white suckers at the

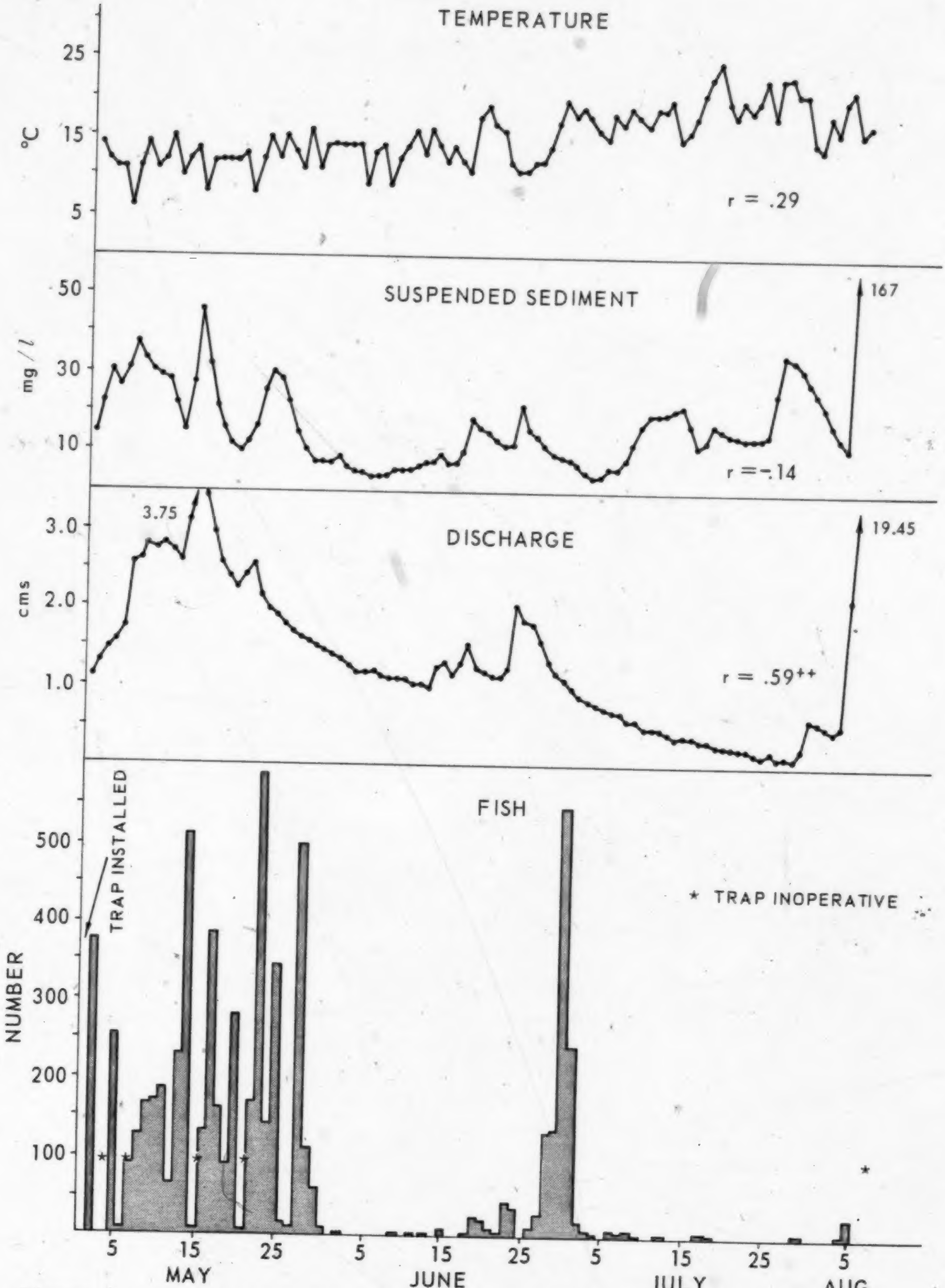

Figure 4. Upstream movement of white suckers at site C, 1976, and daily values for discharge, concentration of suspended sediment, and maximum stream temperature. Partial correlation coefficients (r) for each variable versus movement are in respective boxes. ++ = r significant, $p < 0.05$.

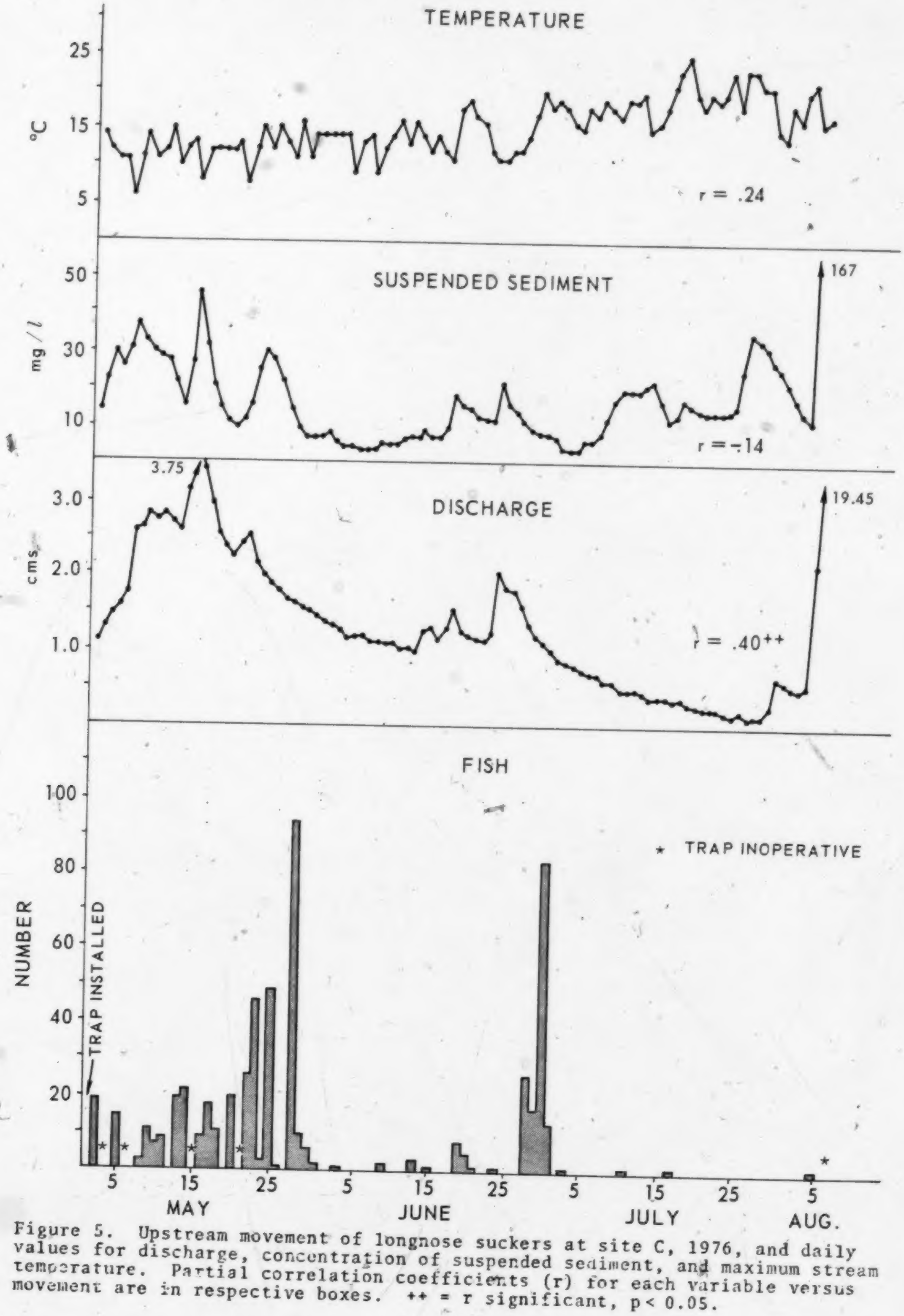

Figure 5. Upstream movement of longnose suckers at site C, 1976, and daily values for discharge, concentration of suspended sediment, and maximum stream temperature. Partial correlation coefficients (r) for each variable versus movement are in respective boxes. ++ = r significant, $p < 0.05$.

upper fence took place (Site D) primarily in May; no mid summer run was evident (Fig. 6). Longnose suckers were not captured at Site D.

Partial correlation analyses indicated a significant correlation between upstream movement (Site C) and discharge (Figs. 4 and 5). Fish in upper reaches of the stream did not appear to respond to temperature or discharge, since upstream movement at Site D was not significantly correlated with discharge or maximum daily temperature. Variation in concentration of suspended sediment was not associated with upstream movement.

Willow Creek was ice free by 16 April, and the discharge was low and the water clear until early May. Water temperatures exceeded 10^{o}C at least twice prior to 2 May when the lower fence was installed. Twelve white suckers were observed in the creek as early as 21 April but none of the pools in the lower 600 m of the creek harboured large concentrations of suckers (such as the schools of fish that appeared during the main migration). The exact date of the start of the spawning run was not determined but suckers probably began entering the creek in the last week of April.

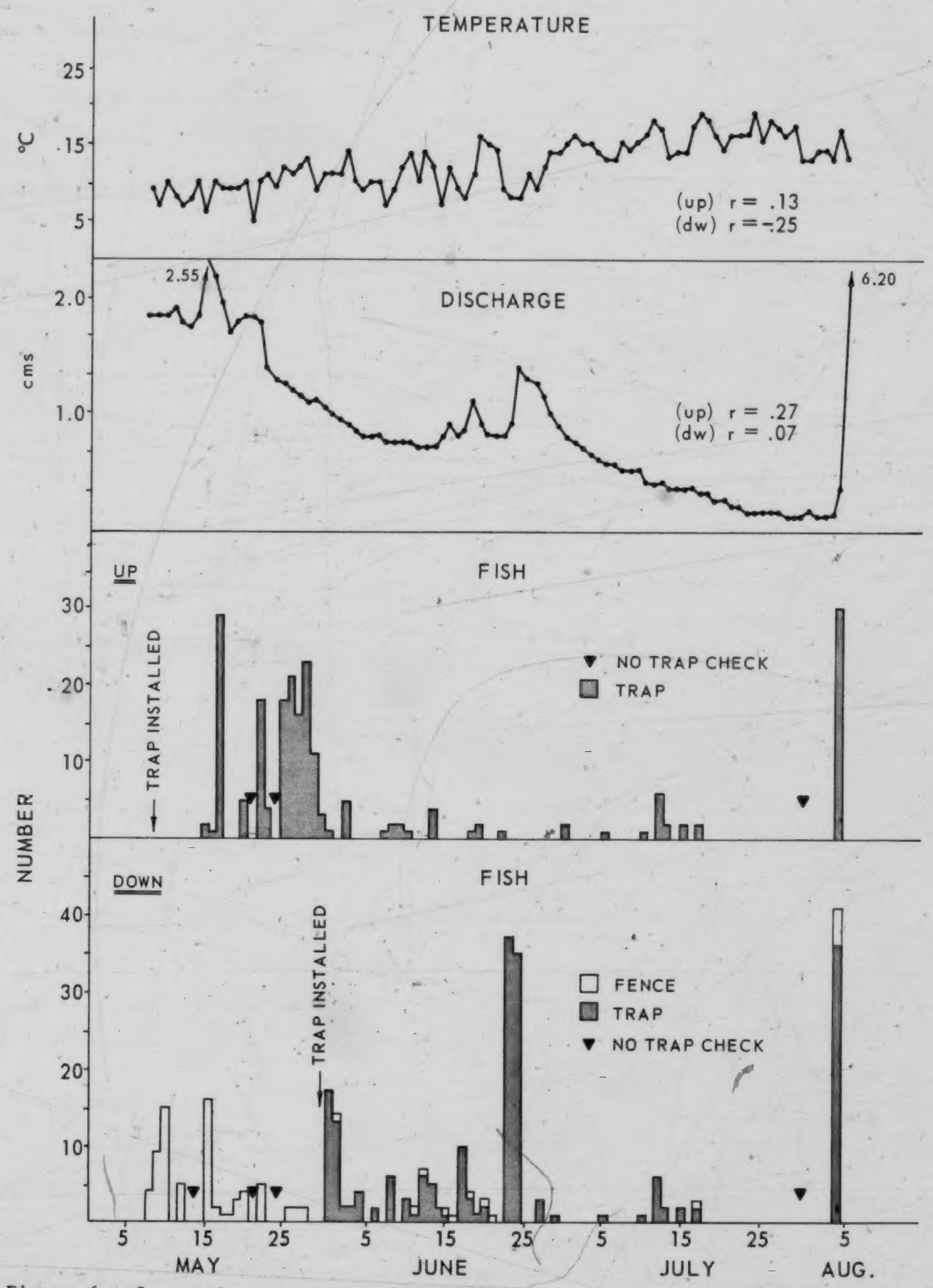

Figure 6. Seasonal movement of white suckers at site D and daily values for discharge and maximum stream temperature. Partial correlation coefficients (r) for each variable versus upstream movement (up) and downstream (dw) are in respective boxes.

On the first day that the Site C fence was operational, 353 white suckers and 15 longnose suckers were captured ascending the creek. Upstream movement was extremely variable from day to day. Upstream movement of white suckers peaked (based on total number of fish per functional trap day for each 7 or 8 day period) between 17 May and 24 May, while longnose suckers ascended in greatest numbers from 25 May to 31 May. At Site D, suckers were first captured on 15 May, eight days after the trap was installed. Peak movement at this location occurred from 25 May to 31 May. By the first week in June, upstream movement at both fences had subsided.

Downstream

The pattern of downstream movement of white suckers was similar to that of longnose suckers at the lower fence (Site C) (Figs. 7 and 8). However, relatively few longnose suckers were captured in May. At the upper fence (Site D), peak movement occurred later than at Site C (Fig. 6). Downstream movement was relatively constant during most of May and June. Longnose suckers were not captured at the upper fence.

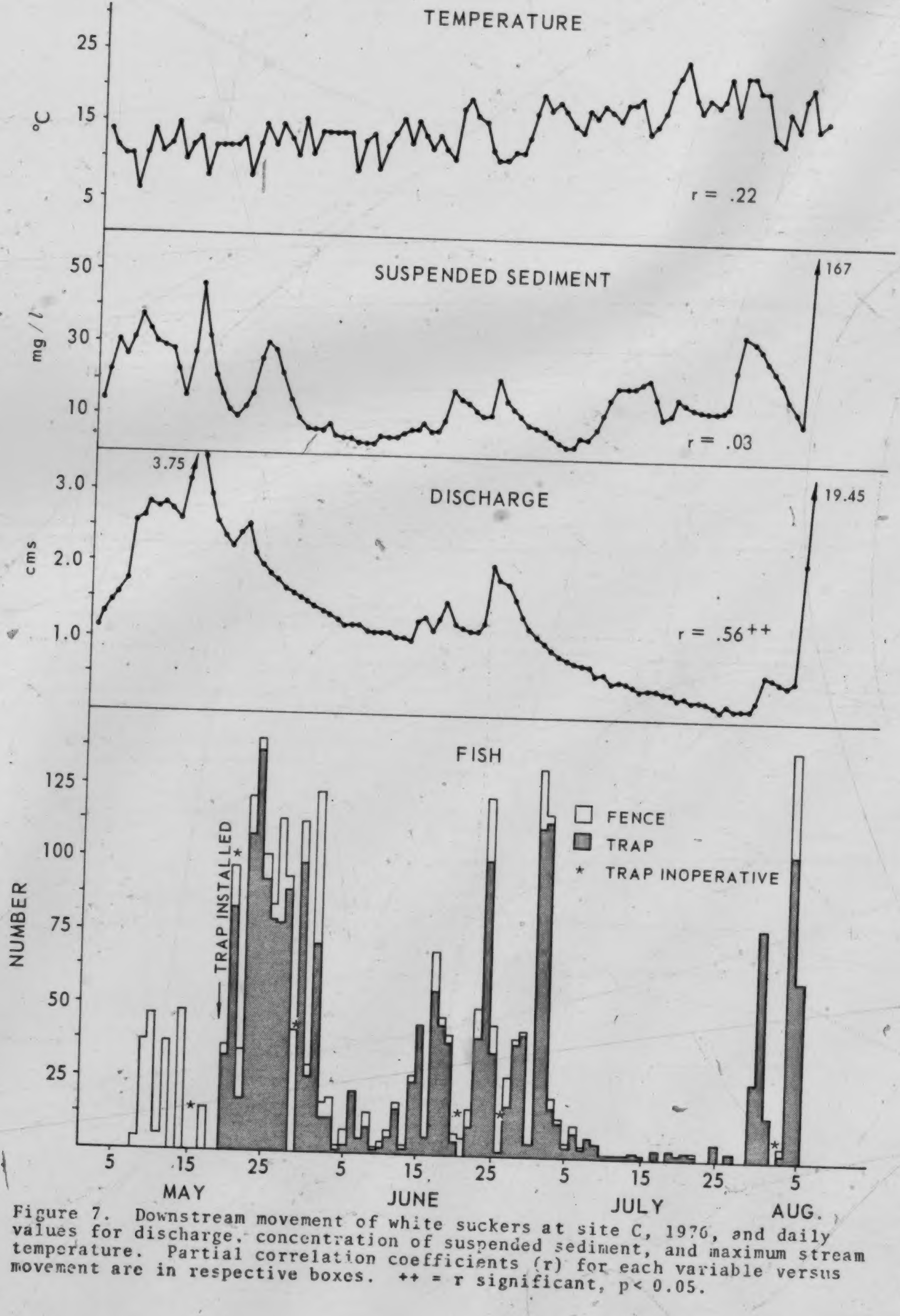

Figure 7. Downstream movement of white suckers at site C, 1976, and daily values for discharge, concentration of suspended sediment, and maximum stream temperature. Partial correlation coefficients (r) for each variable versus movement are in respective boxes. ++ = r significant, $p < 0.05$.

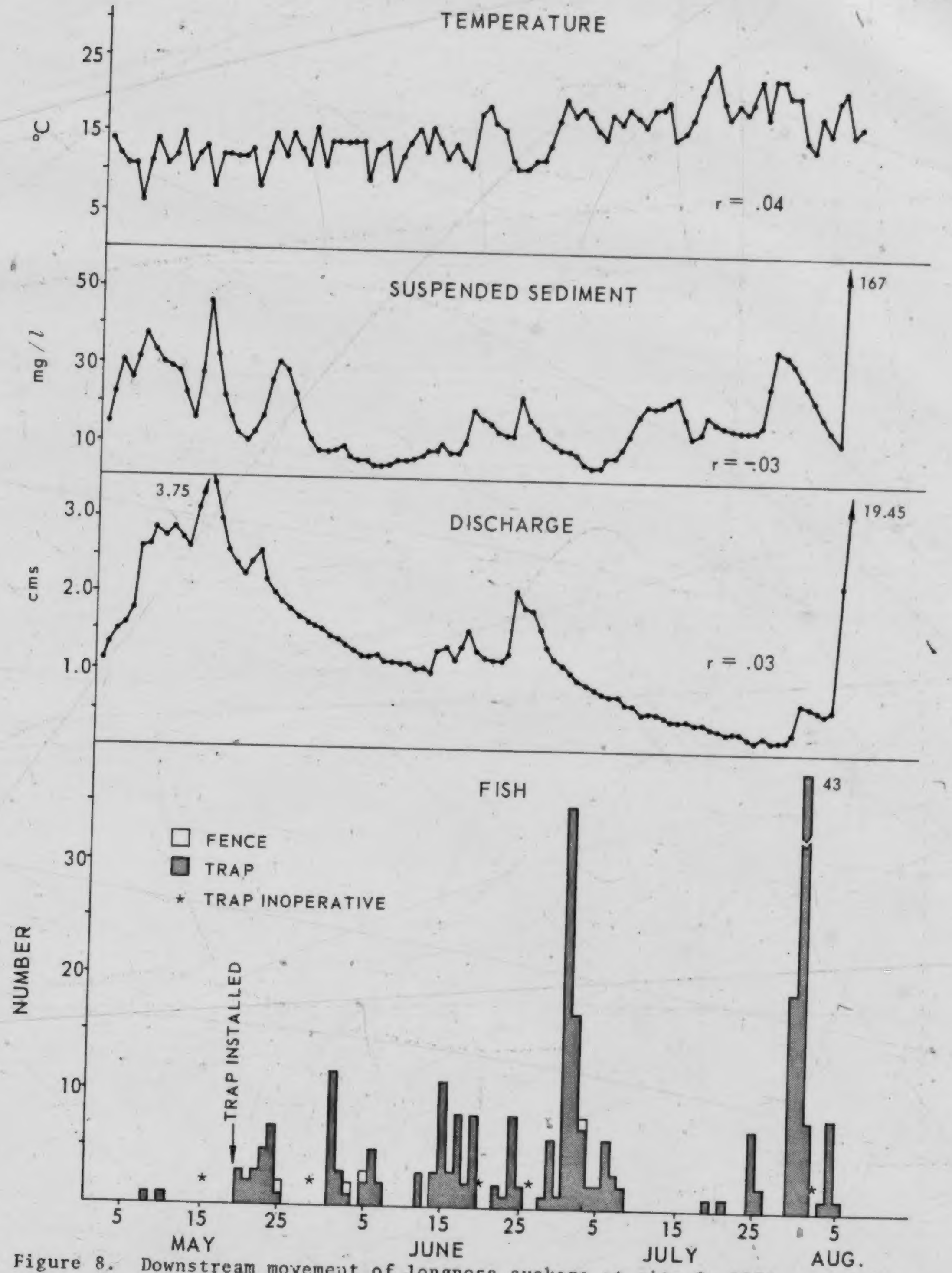

Figure 8. Downstream movement of longnose suckers at site C, 1976, and daily values for discharge, concentration of suspended sediment, and maximum stream temperature. Partial correlation coefficients (r) for each variable versus movement are in respective boxes.

Variation in downstream movement of white suckers at Site C was correlated with discharge (Fig. 7). Daily maximum temperature and concentration of suspended sediment did not seem to influence downstream movement. Downstream movement of longnose suckers at Site C and of white suckers at Site D was not correlated with the factors tested.

Initial movement of suckers occurred at both fences before traps were installed. While the Site C trap was operational, the rate of movement of white suckers peaked in the last week in May. Peak downstream movement of longnose suckers did not take place until the first week in July. At Site D, white suckers descended in greatest numbers during the third week in June. After June there was very little movement at either fence until a freshet in early August.

Statistics of Migrants

Ripe suckers migrated upstream from early May to late June (Fig. 9). In 1975, unlike 1976, ripe fish were caught later in the summer, probably because the spawning run was delayed by the late spring. Migrant males of both species generally became fully ripe sooner than females,

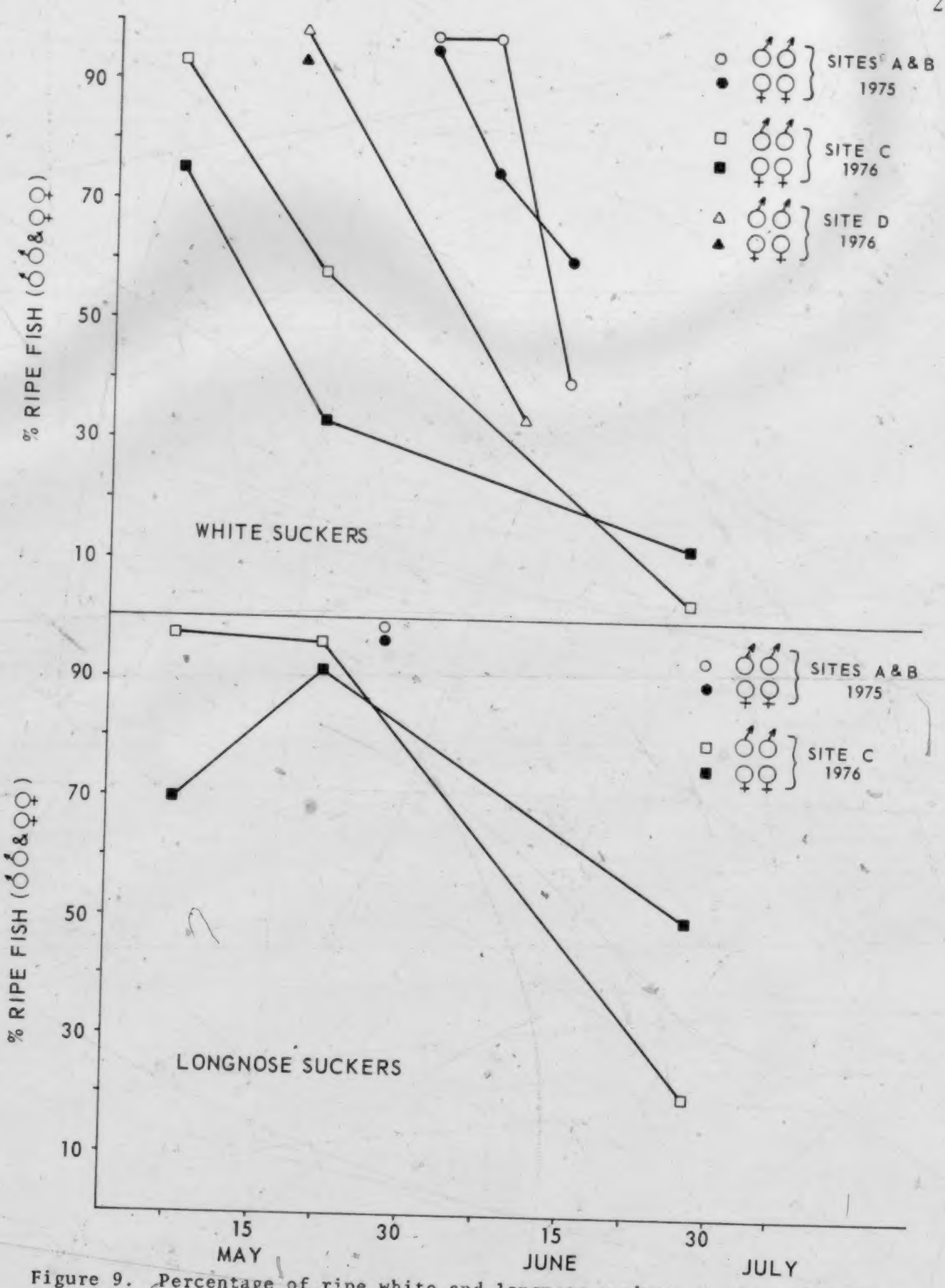

Figure 9. Percentage of ripe white and longnose suckers caught and sampled from upstream traps during 1975 and 1976.

and ripe females were collected later in the summer than males. Female white suckers also migrated upstream later than males (Table 1). Ripe white suckers were caught moving downstream at Sites C and D during May and in the first half of June. Peak upstream and downstream movement of white suckers occurred later in upper reaches. By the beginning of July, most migrants of both species were spent.

The sex ratio of white suckers was 1.6 males to 1 female which was significantly different from a 1:1 ratio ($p<0.05$, $n=1362$). The sex ratio of longnose suckers was not significantly different from a 1:1 ratio ($p>0.05$, $n=196$).

Male white suckers had a mean fork length of 308±0.7 mm and a mean weight of 346.5±2.6 g. Female white suckers had a mean fork length of 326±1.3 mm and a mean weight of 417.4±4.6 g. The mean fork length of male longnose suckers was 317±1.8 mm and the mean weight was 355.9±5.5 g. Female longnose suckers had a mean fork length of 345± 2.4 mm and a mean weight of 459.4±9.3 g. Females of both species were significantly larger (length and weight) than males ($p<0.05$).

During May, male white suckers that migrated upstream at Site D were significantly heavier ($p<0.05$) than males

Table 1. Sex ratios of white suckers migrating upstream at site B, based on samples taken from 21 May to 4 June, 1975.

	MALES	FEMALES	RATIO
FIRST HALF 21-27 May	205	70	2.93
SECOND HALF 28 May-4 June	147	124	1.18

at Site C (Table 2). A run of smaller fish that entered the creek near the end of June was not accompanied by a similar migration in upper reaches. Suckers that entered the creek in June were significantly smaller ($p<0.05$) (length and weight) than the fish that migrated earlier in the spring (Table 2). Less than 10% of the late June migrants were ripe: most were either immature or spent. In both years, in lower reaches of the creek, there was a trend for smaller white suckers to ascend the creek later in the season. This lowered the overall mean size of the upstream migrants. Downstream migrant white suckers, in both years, were consistently larger than upstream migrants at Sites A, B, and C. For longnose suckers, only downstream migrant males were significantly larger than upstream migrant males in 1975 ($p<0.05$).

White suckers ranged in age from III to XII years and longnose suckers were aged from IV to VIII years (Fig. 10). Upstream migrants had a modal age class of VI; however, there were fewer V year old white suckers caught at Site D compared to those captured at Site C. Downstream migrant white suckers had modal age classes of V at Site D and VI at Site C. Older age classes were dominated by females.

Table 2. Mean fork lengths and weights of white suckers sampled; from site C upstream and downstream traps; and from site D upstream and downstream traps, 1976. >>= significantly larger, $p<0.05$. Numbers in parentheses indicate sample size.

LOCATION	x̄ FORK LENGTH (mm)					x̄ BODY WEIGHT (g)				
	May		June	Summer		May		June	Summer	
	up	down	up	up	down	up	down	up	down	
					♂♂					
Site C	310±2.8 (85)	310±5.3 (24)	291±4.5 (45)	303±2.6 (130)	>> 320±3.0 (63)	340±9.7 (45)	334±16.4 (24)	275±11.0 (45)	385±12.9 (130)	>> 375±10.6 (63)
	└----	-->>--	----┘		^ ^	└----	-->>--	----┘		^ ^
Site D				316±2.4 (40)	>> 293±5.0 (41)	└------	------>>	--------	→394±9.8 (40)	>> 282±13.1 (41)
					♀♀					
Site C	333±3.8 (59)	327±17.1 (7)	310±5.6 (43)	323±4.1 (102)	>> 340±4.2 (55)	428±17.5 (59)	421±68.0 (7)	326±14.7 (43)	385±12.9 (102)	>> 450±15.[illegible] (55)
	└----	-->>--	----┘		^ ^	└----	-->>--	----┘		^ ^
Site D				324±5.4 (21)	>> 305±5.7 (39)				433±20.5 (21)	>> 323±15.7 (39)

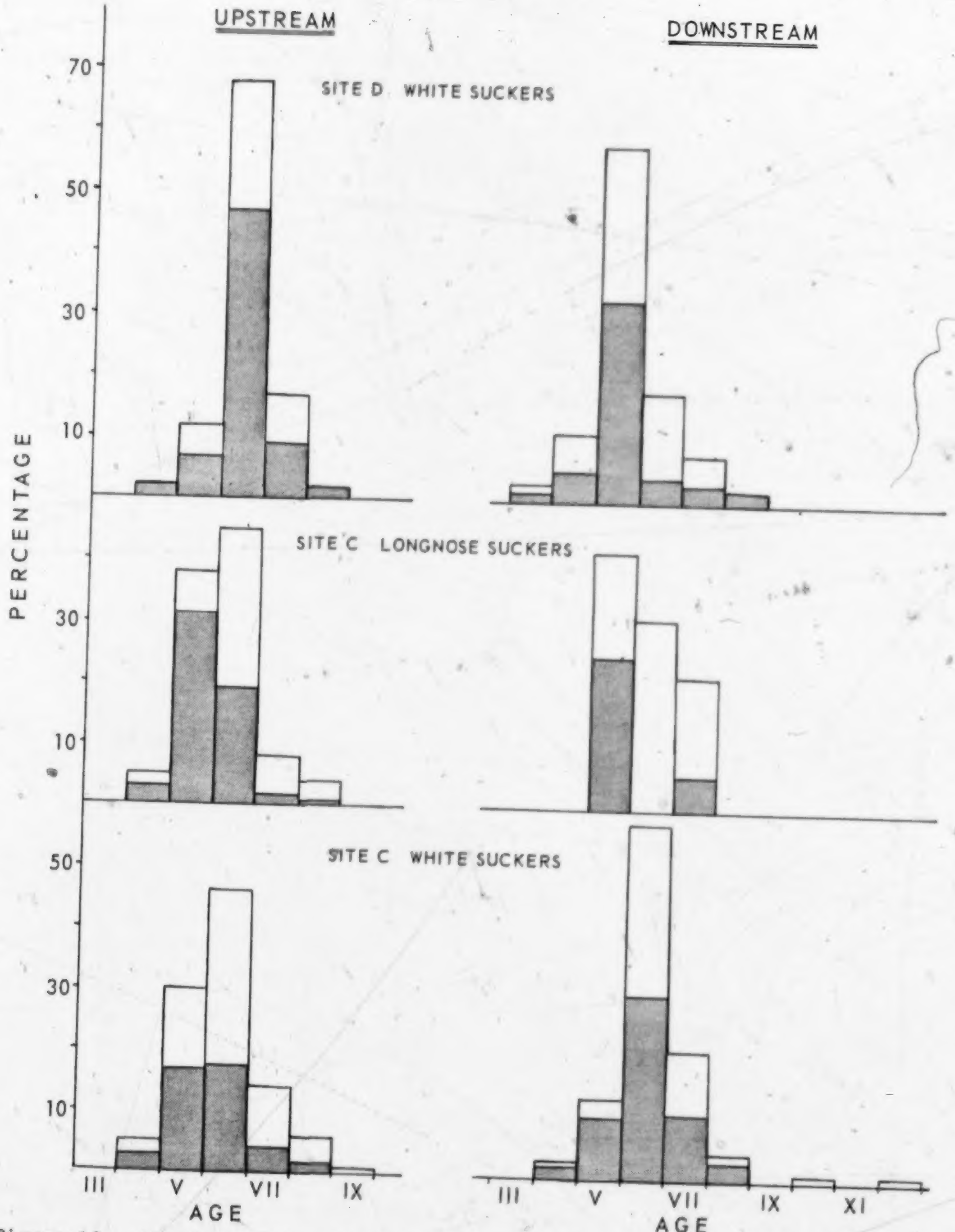

Figure 10. Age frequencies of white suckers (WS) and longnose suckers (LS) sampled from upstream and downstream traps at site C; and white suckers (WS) sampled from upstream and downstream traps at site D. Stippled bars represent males and open bars represent females.

Enumeration and Tagging - Sites C and D

Upstream and downstream traps were in operation at both fences from May to early August in 1976 (Table 3). During that time, there was net immigration of suckers into Willow Creek past the lower fence. In upper reaches of the creek there was net downstream movement. Of the 6475 white suckers caught migrating upstream at Site C, 678 were removed during diel trap checks and or for sampling; the remainder (5797) were released. Some 381 of the 561 longnose suckers captured ascending the creek were released. The ratio of white suckers to longnose suckers (all traps) was 11:1.

The total number of white suckers captured at Site D (both traps) represented about 5% of the total captures at Site C. There was apparently very little mixing of fish from upper and lower parts of the creek in one season. White suckers tagged (3068) and clipped (928) at the lower site did not reach the upper fence. At Site D, of 115 fish tagged and 104 clipped, only 2 tagged and 2 clipped fish were recaptured at the lower fence. Both tagged fish were released on 6 June and one was recaptured 5 days later while the other was not recaptured for 41 days.

Table 3. Functional trap days and total captures of white suckers and longnose suckers at sites C and D, 1976. Numbers in parentheses represent the days each fence was in place.

LOCATION	DAYS	WHITE SUCKERS	LONGNOSE SUCKERS
SITE C-UP	88	6475	561
SITE C-DOWN	75(88)	3286	306
SITE D-UP	74	202	-
SITE D-DOWN	59(79)	303	-

During the spawning migration in May, 2140 white suckers and 108 longnose suckers were tagged and released at the Site C upstream trap. Early migrant white suckers remained upstream longer than later migrants (Table 4). On the other hand, early migrant longnose sucker spent less time in the creek than later migrants (Table 4).

White suckers tagged at the lower fence were recaptured upstream to section 103 (10.3 km). There was a relatively constant rate of upstream movement (Table 5). Early migrants moved farther upstream than later migrants but had more time to do so. The majority of white suckers were recaptured within 3.0 km of the Site C fence: 68% were recaptured in the first 3.0 km, 19% were recaptured in the next 3.0 km, 12% were recovered in the adjacent 2.9 km, and 1% were recaptured in the last 2.1 km. Tagged longnose suckers were recaptured upstream to section 11 (1.1 km).

Dilution of marked fish by the addition of unmarked fish represented less than 5% of the population estimate; therefore, population estimates were calculated without adjusting for dilution. The estimated number of white suckers in the 11 km above the Site C fence during May was 11,390, with an upper confidence limit of 13,670 and

Table 4. Mean length of time spent in the stream by white suckers and longnose suckers tagged (upstream trap) and recovered (downstream trap) at Site C, 1976.

WHITE SUCKER	
DATES TAGGED	NO. DAYS TO RECAPTURE ($\bar{x}$)
May 5-8	25
May 9-16	22
May 17-23	12
May 25-30	11

LONGNOSE SUCKER	
DATES TAGGED	NO. DAYS TO RECAPTURE ($\bar{x}$)
May 20	11
May 23	7
May 28	18
May 30	32

Table 5. Upstream movement of white suckers and longnose suckers based on individuals tagged in May at site C and recaptured by electroshocking 31 May-2 June and 9 June, 1976.

WHITE SUCKERS					
DATE TAGGED	NO. TAGGED	NO. RECAPTURED	$\bar{x}$ DISTANCE (100 m)	MIN-MAX (100 m)	
5	205	1	59.0	-	-
8	84	3	44.3	10	71
9	97	5	38.2	4	80
10	38	6	46.5	2	90
13	149	7	45.6	4	103
16	75	1	10.0	-	-
17	196	11	17.7	2	59
18	149	12	32.2	2	73
19	88	8	33.0	11	78
20	276	18	30.5	2	87
23	284	9	22.4	2	59
25	149	5	5.2	2	10
28	251	16	4.6	2	11
29	50	4	12.5	2	28
30	49	4	3.0	2	4

...continued

Table 5. concluded.

LONGNOSE SUCKERS

DATE TAGGED	NO. TAGGED	NO. RECAPTURED	$\bar{x}$ DISTANCE (100 m)	MIN-MAX (100 m)	
10	1	0	-	-	-
17	7	0	-	-	-
19	11	1	2.0	-	-
20	19	0	-	-	-
23	16	1	11.0	-	-
28	48	2	4.0	4	4
30	6	1	4.0	-	-

a lower limit of 9,492 (95%). The number of longnose suckers in this same part of the stream was estimated at 773, with an upper limit of 1486 and a lower limit of 365 (95%).

Diel Movement

Virtually all upstream and downstream movement of suckers took place at night (Figs. 11 to 14). There was so little variation in discharge, and presumable in concentration of suspended sediment, over a 24 hr period (Water Survey of Canada 1975-76 unpublished data) that these factors were not considered important cues in controlling diel movement. Temperature may have influenced diel movement. There was a significant negative correlation with movement of white suckers ($r=-.4101$, $p<0.01$) and temperature. Movement commenced each day after the maximum water temperature had been reached, and movement ceased the next morning when water temperature began rising. This association of temperature with movement may, however, be a function of light intensity, because daily movement was more closely related to dusk and dawn than with changes in temperature. There was more daytime movement during freshets, especially in the downstream direction (i.e., June 18-19, Fig. 12).

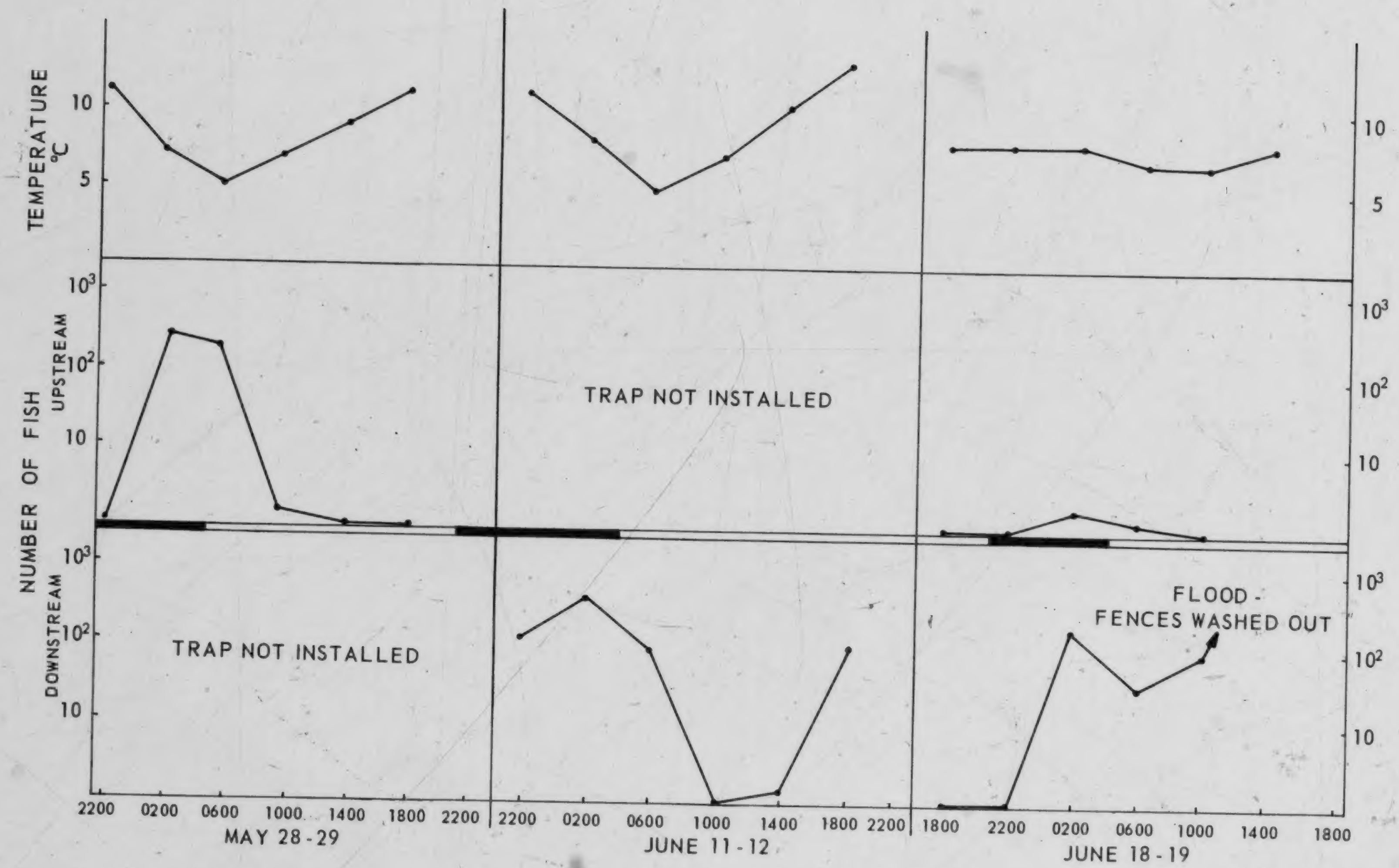

Figure 11. Diel movement of white suckers at sites A and B, 1975. Horizontal black bars indicate dark hours.

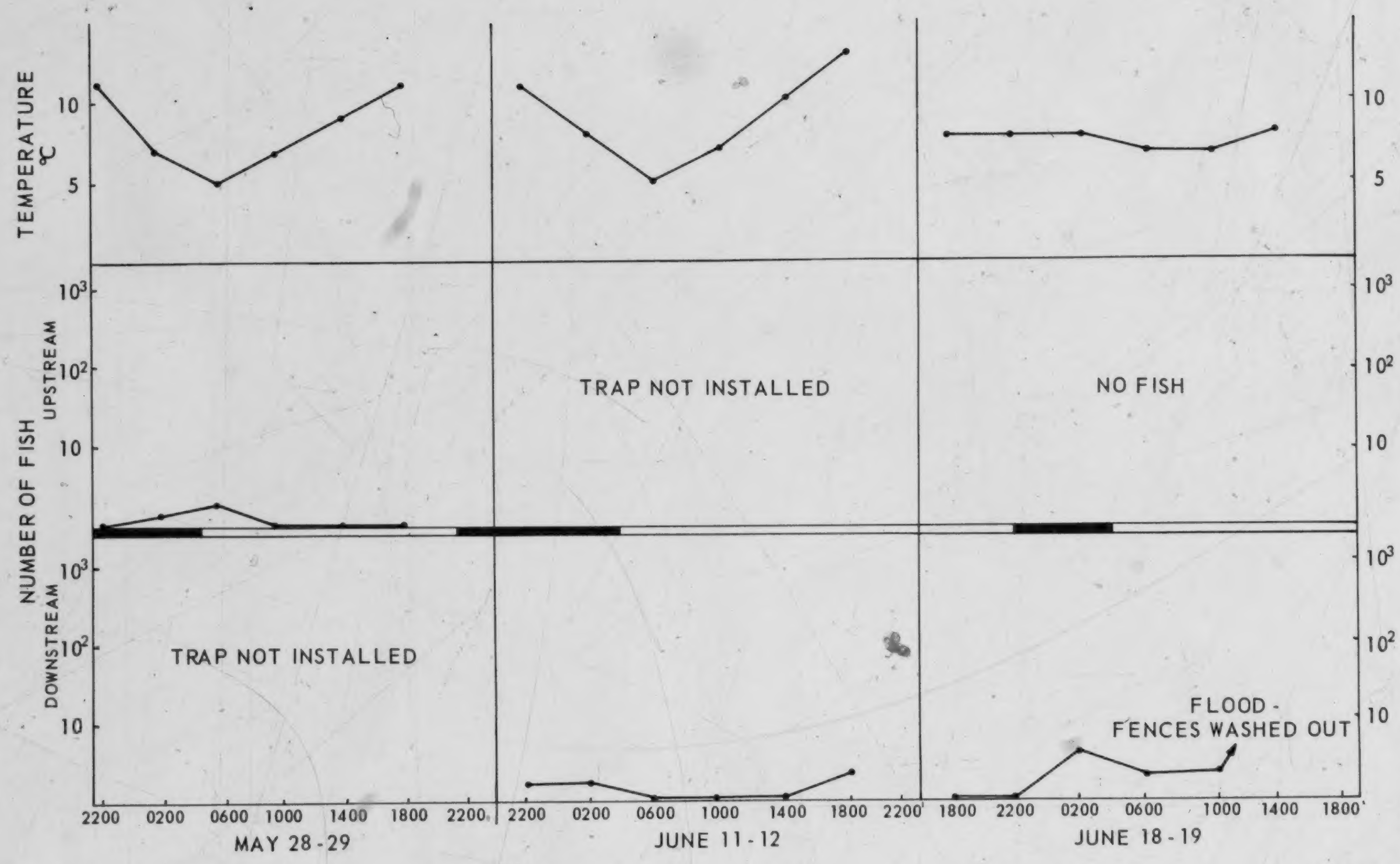

Figure 12. Diel movement of longnose suckers at sites A and B, 1975. Horizontal black bars indicate dark hours.

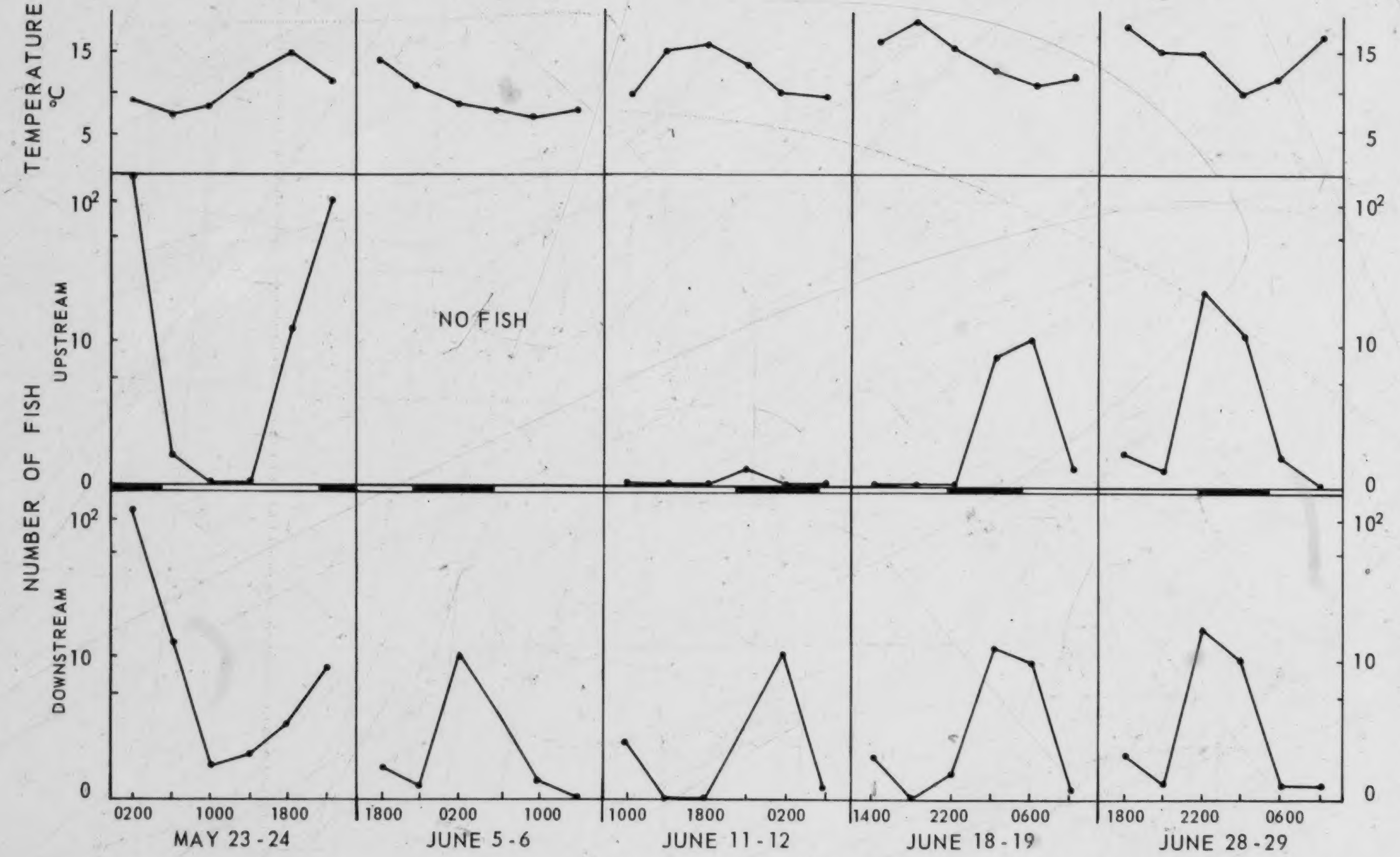

Figure 13. Diel movement of white suckers at site C, 1976. Horizontal black bars indicate dark hours.

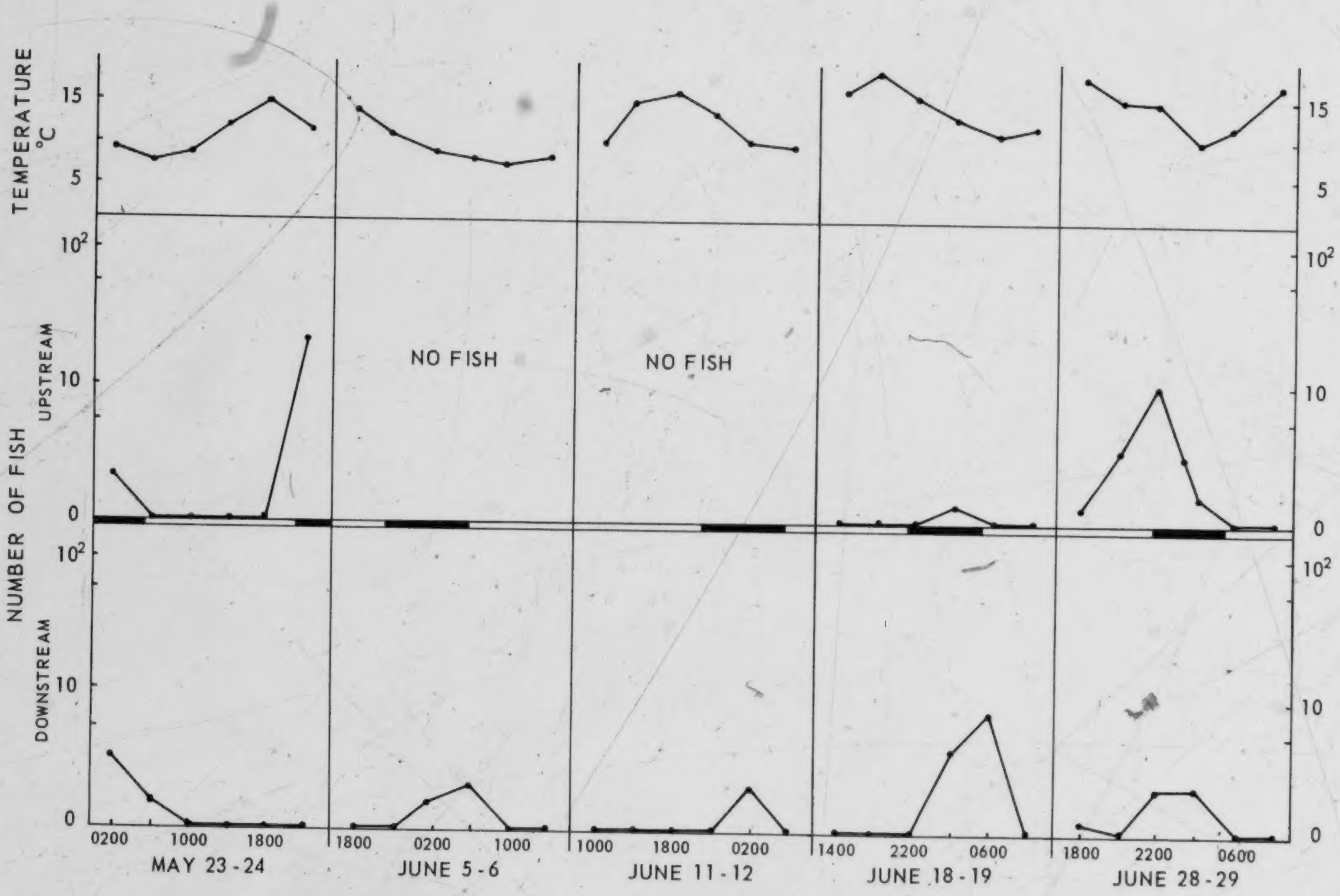

Figure 14. Diel movement of longnose suckers at site C, 1976. Horizontal black bars indicate dark hours.

DISCUSSION

Seasonal movement of white suckers and longnose suckers was closely associated with discharge. There was a positive correlation with discharge and upstream movement of both species. Downstream movement of white suckers, but not of longnose suckers was also positively correlated with discharge. Although discharge is related to upstream movement of suckers, current velocity must reach a point where it inhibits movement. Migrating fish could not be captured during freshets but extreme high water probably subdued upstream movement and increased downstream movement. Suckers ascending the creek into upper reaches did not respond to increasing temperature or discharge. The onset of the spawning migration in the lower reaches of Willow Creek appears to be related to increasing temperature moreso than discharge: initial movement began when water temperature first exceeded 10°C.

Inconsistent results from two year's data may indicate that other factors might be responsible for governing movement. Hoar (1953) points out that physiological condition is implicated in migration. In other words, fish must be physiologically prepared to spawn before they will move. Subtle endogenous changes in suckers may then be important prerequisites to migration.

Initial spawning movements of white suckers occur at temperatures ranging from 7 to 10°C; spawning movements of longnose suckers start at temperatures ranging from 5 to 9°C (Bond 1972; Brown and Graham 1953; Geen *et al*. 1966; Raney and Webster 1942; Rawson and Elsey 1948). Dence (1948) found that the migration of the dwarf white sucker *Catostomus commersoni utawana* usually began 20 days after total ice melt. Longnose suckers sometimes migrate at lower temperatures than white suckers (Geen *et al*. 1966), but in Willow Creek longnose suckers moved upstream slightly later than white suckers.

Few researchers have examined the effects of streamflow on movement; consequently, it is often thought that temperature is the main abiotic factor controlling movement of suckers (Bailey 1969; Bond 1972; Brown and Graham 1953; Dence 1948; Nelson 1968; Raney and Webster 1942; Rawson and Elsey 1948). Furthermore, few if any studies have dealt with migration after spawning. Geen *et al*. (1966) examined seasonal movement of white and longnose suckers, and they concluded that temperature was the most important factor governing stream movement and that water level (discharge) did not play as important a role.

The influence of discharge and water temperature may not be totally divorced. The findings of this study indicate that temperature may induce initial upstream movement after which variations in discharge regulate the degree of upstream movement and, in part, downstream movement.

White and longnose suckers are night active in lentic waters. Both species move inshore at dusk and offshore at dawn (Hayes 1956; Raney and Webster 1942; Spoor and Schloemer 1938). In Willow Creek most of the movement was nocturnal. Bassett (1957) also observed this phenomenon, but Geen *et al.* (1966) found that downstream diel movement was related to temperature rather than changes in light. Campbell's (1971) temperature controlled laboratory experiments showed that white suckers are most active in the dark. The ecological significance of this nocturnal movement is not clearly understood. Suckers move inshore at night to feed (Dence 1948) and also to spawn (Hayes 1956). Inshore movements during the spring probably aid fish in locating spawning streams. Nocturnal instream movements may also reduce predation, particularly since suckers migrate in large schools during spawning time. Nocturnal movement may be a result of selective pressure caused by predation.

White and longnose suckers migrate upstream primarily in May and June (Scott and Crossman 1973). This was also the case at Willow Creek, and, in general, the statistics of the migrants were similar to those reported in the literature. Males are more numerous in most spawning stocks although sex ratios are usually not significantly different from a 1:1 ratio (Bailey 1969; Basset 1957; Bond 1972; Spoor 1938). At Willow Creek males were more numerous in younger age classes, as is generally observed (Brown and Graham 1953; Spoor 1938), while females tended to dominate the older age groups: the year classes of V and VI represented the majority of the migrants. The age structures of migrant suckers reported in the literature show considerable variation; however, in most populations fish first migrate when they are V or VI years old (Geen 1958; Geen *et al*. 1966). Modal age classes of V and VI have been reported for white and longnose suckers in several studies (Brown and Graham 1953; Bailey 1969; Raney and Webster 1942; Spoor 1938).

Beamish (1973) documented a wide range in size at sexual maturity between different populations of white suckers. Similarly, different longnose sucker populations exhibit some variation in size and age at sexual maturity (Harris 1962; Bailey 1969; Tripp and McCart 1974). The most consistent trend for suckers is that after sexual maturity females are normally larger than males. At Willow Creek this was the case for white and longnose suckers.

Upstream migrants passing Site C in May represented roughly half of the population in the 11 km of stream above the Site C fence. Most migrants were recaptured in the lower 3.0 km of the stream. White suckers that entered the creek early migrated farthest upstream and tended to remain in the stream the longest, but the reverse was true for longnose suckers. Others have noted that early migrant white suckers remain upstream longer than later migrants (Geen 1958; Geen *et al*. 1966). Raney and Webster (1942) found that white suckers in the first part of a spawning run ascended the creek much farther than fish in the latter parts of the run. Presumably, fish that migrate early should be less ripe than those that migrate later in the season, and "green" fish may move until they are ripe enough to spawn. Bond (1972) showed that female white suckers migrated later than males which may be related to females taking longer to reach full spawning condition. In Willow Creek, migrant males were generally closer to being ripe than females, and females migrated later than males.

Not all migrants returned downstream after spawning. In the lower reaches of Willow Creek there was net movement into the stream. A number of these suckers apparently overwinter in the stream and migrate upstream following spring break-up. Upstream migrants captured at Site D were probably winter stream residents, because during the summer of 1976 fish tagged at the lower fence (Site C) did not ascend the creek to the upper fence (Site D), which suggests that fish entering the creek from the reservoir do not move into upper reaches in one open water season. There was very little mixing of fish from upper and lower reaches of the creek; however, there was no indication that spawners migrating into upper reaches of the creek were greatly different in size or age than those in the lower parts of the creek. Immature fish did not migrate into the upper reaches of the creek, and those immature fish captured moving downstream at Site D were likely part of a small stream resident population. Peak upstream and downstream movement took place later in upper reaches, and this may support Bond's (1972) speculation that white suckers in upper reaches of a stream spawn later than those near the mouth.

White suckers were far more abundant than longnose suckers in Willow Creek. White suckers inhabited all parts of the stream whereas longnose suckers tended to remain in the lower reaches: longnose suckers were not captured at the upper trap site. The reason for this imbalance is not known, although reference to past findings may provide some explanations.

White suckers and longnose suckers coexist in various habitats but white suckers are generally more abundant in reservoirs (Bassett 1957; Hayes 1956; Nelson 1965). In some natural lakes longnose suckers outnumber white suckers (Geen *et al*. 1966; Dietz pers. comm.). Longnose suckers are also more abundant at higher latitudes (McPhail and Lindsey 1970) which suggests that longnose suckers have a lower preferred temperature than white suckers. Nelson (1965) and Roberts (1975) also refer to the lower temperature preference of longnose suckers. Both species spawn in lakes as well as in streams (Hayes 1956; Rawson and Elsey 1948), but longnose suckers are probably better adapted to running waters. Both species are preyed upon by similar piscivores, (Scott and Crossman 1973) and predators likely take either species with equal preference.

White suckers are more abundant than longnose suckers in Chain Lakes Reservoir and upper Willow Creek probably because of the impoundment. Although both species are capable of beach spawning, white sucker eggs may have better hatching success in the reservoir. During the summer the reservoir, because it is relatively shallow, warms to over 16°C (bottom). Higher temperatures probably benefit white suckers since they prefer warmer water than longnose suckers. Rainbow trout are the major predatory fish species in the reservoir, but, because of the high sucker to trout ratio, trout are probably not effectively able to cull either of the sucker species. The diets of suckers are similar (Hayes 1956) and even subtle differences in food habits should not result in a great species imbalance between white and longnose suckers.

Nelson (1965) was unable to explain a decrease in longnose suckers with a subsequent increase in white suckers in Lower Kananaskis Reservoir, Lac des Arcs and Gap Lake. He felt that white suckers were better adapted to fluctuating reservoirs. There is probably no single reason for white suckers being dominant over longnose suckers in Chain Lake Reservoir; overall it appears that the physical and biological features of impoundments are best suited for white suckers (at least in southern Alberta).

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CHAPTER II Spawning behavior and early life history of white suckers, *Catostomus commersoni*, and longnose suckers, *C. catostomus*, in Willow Creek, Alberta

ABSTRACT

Spawning behavior, embryological development, and fry movements of white suckers, *Catostomus commersoni*, and longnose suckers, *C. catostomus*, were studied at Willow Creek, Alberta. Spawners entered the creek in May, and by early August the fry of both species had drifted out of the creek. The spawning behavior of both species was similar. Sexual dimorphism was more obvious in longnose suckers than in white suckers. Eggs of both species were successfully fertilized and embryos were reared to hatching. White suckers hatched in 15 days at 10°C ($\bar{x}$); the incubation period of longnose suckers was 14 days at 12.02°C ($\bar{x}$). Major embryonic stages of both species were determined and there were no gross morphological differences between the two species. After hatching, larvae remained in the gravel for about 11 days. Larvae emerged from the gravel with shrunken yolk sacs, partially inflated swim bladders, and well developed pectoral fins. Soon after their departure from the substrate larvae (fry) drifted

downstream. Fry moved downstream near the surface and were most numerous in the fast water. The mean size of fry caught in drift nets was 12.1 mm. Fry moved downstream primarily during the night. Diel movement was not associated with variations in temperature, discharge, or concentration of suspended sediment. A chronology of spawning and early life history was formulated from back calculation of seasonal drift data.

INTRODUCTION

White and longnose suckers are gregarious, polyandrous spawners, and their mating behavior has been described by Bond (1972), Geen *et al.* (1966), and Reighard (1920). Somewhat less is known of the early life history of both species, in particular that of the longnose sucker. Embryological development of the white sucker was first described by Stewart (1926). Later, Long and Ballard (1976) documented, with illustrations, the rates of embryonic development at different temperatures. Mansueti and Hardy (1967) also illustrated various embryological stages of the white sucker. No such literature is available on the longnose sucker although the duration of incubation has been reported by Geen (1958) and Geen *et al.* (1966).

Previous studies on the behavior of larval white and longnose suckers have dealt primarily with movement. Downstream movement of larvae, first noted by Hubbs and Creaser (1924), was subsequently studied by Bassett (1957), Geen (1958), and Bond (1972). A more detailed study by Geen *et al.* (1966) examined both seasonal and diel movement of sucker fry. Further observations by Clifford (1972) revealed a relationship between the size of fry and their location in the water column as they moved downstream.

With the exception of Geen *et al.* (1966) and Clifford (1972), detailed studies on the incubation and seasonal movement of sucker fry are lacking. This chapter reports on the spawning behaviour, embryological development, and larval movements of white and longnose suckers. Particular emphasis was placed on establishing a chronology of spawning, incubation, and downstream movement of fry.

STUDY AREA

The study area is approximately 90 km south of Calgary in the east slope of the Rocky Mountains of Alberta. Field studies were carried out on the lower 600 m of Willow Creek above Chain Lakes Reservoir (lat. 50^{o} 11' 47" N, long. 114^{o} 12' 46" W). The creek has a drainage area of 162.7 km^2 and a gradient of 8.37. Mean daily discharge (over a 9 year period) is 1.14 m^3/sec (Water Survey of Canada 1974). The average width of the creek is 10 m and mid-summer depths range from a few centimeters to over 2.5 m in deeper pools. The most common species of fish inhabiting the creek are: white suckers, longnose suckers, and rainbow trout, *Salmo gairdneri*.

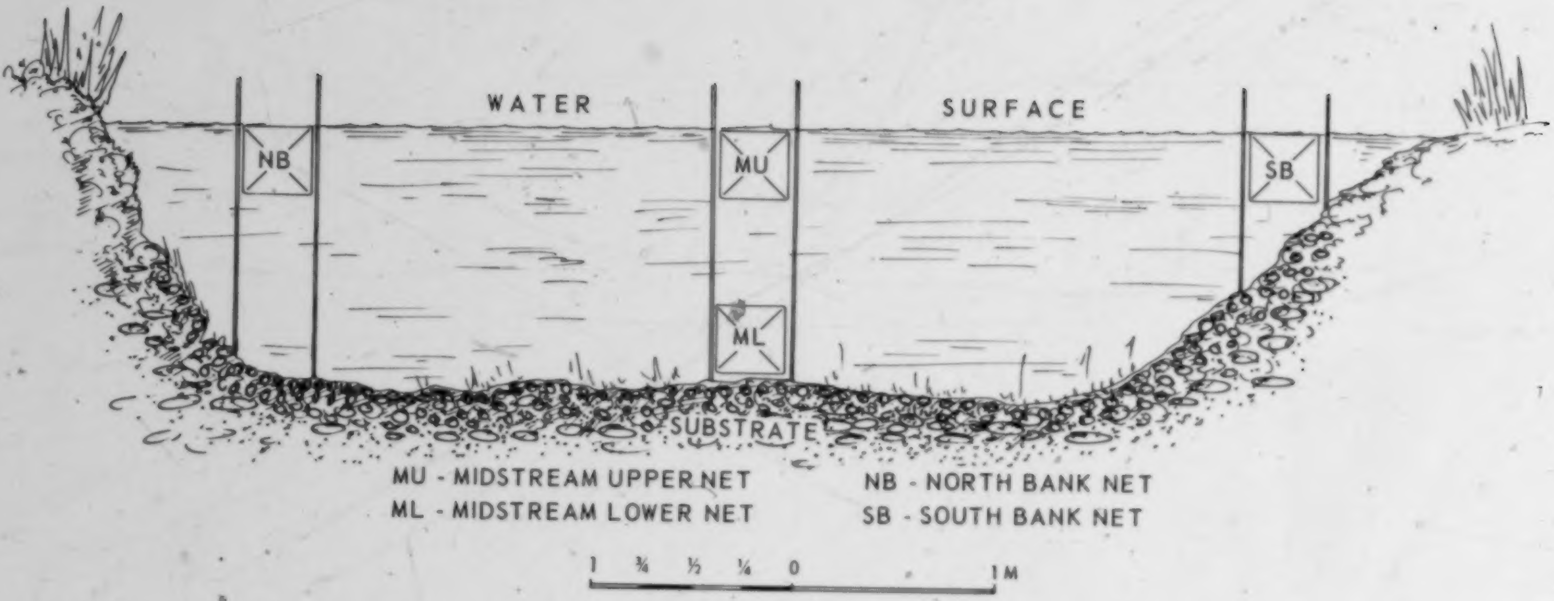
MATERIALS AND METHODS

Field studies were carried out from May to August, 1976. Most spawning observations were made on a riffle 400 m upstream from the mouth of the creek. The observation station was usually visited at least once a day, and night observations were made several times during the spawning period. Each observation period was 15 minutes, and photographs were taken to supplement notes. A standard Surber sampler was used to collect fertilized eggs from the riffle in the observation area.

Incubation experiments were carried out on both species in the field, and only on white suckers in the laboratory. Eggs were dry fertilized with milt from at least two males. Eggs were allowed to water harden before being placed in a cylindrical egg tray as described by Ash (1974). The tray was then placed in a small riffle, anchored, and disturbed only once a day when a sample of 20 eggs was removed. The white sucker eggs incubated in the laboratory were part of the same brood incubated in the stream. In the laboratory, eggs were placed in aerated incubation jars and reared at a constant temperature of $10^{o}C$. A sample of 50 eggs was taken from laboratory incubation jars daily and fixed. Prior to fixing, embryos were examined and the stage of development noted. Embryos were fixed either in 10% formalin or Smith's Fixative. In the laboratory, embryos divested of their egg cases were examined and described after Long and Ballard (1976).

Sucker larvae moving downstream were caught in drift nets 30.5 cm x 30.5 cm at the mouth with a mesh aperture of 800 μ^2. Drift nets were suspended in the stream on two vertical metal rods. All nets were situated about 200 m upstream from the creek mouth. Up to four nets were used at times, but normally only only two were used: midstream upper and midstream lower. When the two additional nets were used they were located within 1 m of either bank in line with the midstream nets (Fig. 1). Water velocity was greatest along the south bank (>1.0 m/sec) and least (<0.5 m/sec) along the north bank: midstream flow was intermediate. A few sucker fry captured in drift nets were placed in field aquaria so their behaviour could be observed.

Diel drift experiments were carried out on four occasions using midstream upper and lower nets. Drift nets were placed in the stream for one hour at the beginning of six four-hour intervals (i.e., 0600, 1000, ...0200). On one occasion the upper net was in place over a 24 hr period, being removed every hour, emptied, and replaced.


WATER
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MU
SB
ML
SUBSTRATE
MU - MIDSTREAM UPPER NET
ML - MIDSTREAM LOWER NET
NB - NORTH BANK NET
SB - SOUTH BANK NET
1 ¾ ½ ¼ 0
1M

Figure 1. Position of drift nets in Willow Creek.

All seasonal data were compiled from captures in midstream upper and lower nets. Samples were taken at 2200-2300 hrs on ten days from 5 June to 3 August. All fry were fixed in 10% formalin and samples were stained with rose bengal solution (1%) (Mitterer and Rearson 1977) prior to counting. Fry and eggs were measured using a microscope fitted with an ocular micrometer. A total of 25 fry from each sample were measured to determine mean length.

Stream temperatures were recorded with a Peabody Ryan 30 day strip-chart recorder. Reference temperatures were also taken each day with a pocket thermometer. Discharge and turbidity data were obtained from Inland Waters Station No. 05AB028 located 600 m upstream from the creek mouth. Times of sunrise and sunset at Willow Creek were obtained from Atmospheric Environment Services. Unpaired student t-tests were used to compare lengths of fry and simple correlation analyses were done on drift net captures versus temperature (Sokal and Rohlf 1969).

RESULTS

Spawning Behavior

Ripe white and longnose suckers entered the stream from May until the beginning of July (Chapter I). White suckers were first observed spawning on 21 May but mating acts were infrequent. Spawning occurred as early as 17 May judging by the appearance of unhatched embryos recovered from gravel beds on 29 May. Spawning took place in the lower 600 m of the creek until 4 July. Peak spawning, based on the frequency of spawning acts and the number of fish in the observation area, occurred between 29 May and 7 June. Spawning longnose suckers were only seen on 17-18 June although they were frequently observed on the spawning beds with white suckers.

Spawning occurred over gravel (1 cm dia.) and larger rocks (20 cm dia.) in a riffle where water depth ranged from 15-30 cm. Water velocity was about 1.0 m/sec. The riffle was immediately downstream from a large deep pool and adjacent to the main channel of the creek. The area under observation was roughly 80 m^2 and the spawning bed represented about 35% of this area.

All spawning took place during the day and the number of spawners in the observation area ranged from 40 to over 200. Males were generally scattered throughout the pool and riffle. A female preparing to spawn would move into a loose aggregation of males and receive immediate recognition. Males generally approached the female from behind, sometimes examining her caudal region prior to assuming a position adjacent to and abreast of her. Soon after this initial movement, the female was accompanied by several males that persisted in gaining and maintaining a position next to her. Larger males were generally better able to hold a position beside a female and they excluded subordinate males to the periphery of the group. This group of fish, a "spawning aggregation," consisted of one female and two to seven males. The female initiated the spawning act with a slow side to side movement of her tail. This movement was patterned by the males and it gradually became faster until all fish were thrashing the water with their tails. At this point, the fins were erect (dorsal most obvious) and quivering while eggs and milt were emitted. This terminal phase of the spawning act lasted for two to five seconds. After the spawning act was completed the group dispersed. Individual females spawned from one to five times during observation periods of 15 minutes.

White suckers were not coloured but sexual dimorphism was evident. Males were generally smaller and more vividly striped than females. Males displayed a darker black lateral stripe under a cream coloured lateral occipital band. Nuptual tubercles (pearl organs) were prominent on the anal and caudal fins of males, but entirely absent from females. Longnose suckers of both sexes had a crimson lateral band but it was generally much brighter on males. Male longnose suckers were usually smaller than females and they had nuptual tubercles similar in placement and shape to those of male white suckers.

Incubation and Embryological Development

White sucker eggs were incubated in the creek from 1 June to 17 June (16 days). Initial hatching took place on day 15 and virtually all embryos were hatched by day 16. The mean water temperature (daily average of minimum and maximum) during the incubation period was 10.0°C. White sucker eggs incubated in the laboratory at 10.0°C hatched in 16 days. Longnose sucker eggs were incubated in the creek from 17 June to 2 July (16 days). Initial hatching occurred on day 14 and most of the remaining embryos hatched on day 15. The mean water temperature during incubation was 12.2°C. The most striking condition in the incubation experiments was the synchrony of hatching. Virtually all hatching took place in a two day period. The shorter incubation time of longnose suckers was attributed to higher water temperatures.

White and longnose suckers had remarkably similar rates of embryological development (Table 1) . Within a few minutes of fertilization the micropyle was evident and eggs were swollen to a diameter of 3.1±.03 mm (n=10) and 2.6±.03 mm (n=10) respectively for white and longnose suckers. Cleavage began within 4-12 hours and by 24 hours the multicelled morula was observable with the naked eye (Plates 1.1, 2.1). The first major transformation in the embryos took place about day 5 at the beginning of organogenesis (Plates 1.3, 2.2, Table 1). At this stage the white embryo could be observed, with the naked eye, upon a much larger yellowish yolk mass. From this point onward the embryo grew rapidly, developing the brain, ears, and heart, and enlarging the tail (Plates 1 and 2, Table 1). Most embryos were active by the 9th day. The eyed stage (pigmented iris) was not reached until latter stages of embryogenesis. In the final stages of development the blood flow was clearly evident, the yolk sac was reduced in size, and pectoral fin buds appeared. Egg cases became

Table 1. Embryological development of white and longnose suckers. *Refer to Plates 1 and 2.

DAY OF INCUBATION	EMBRYONIC STAGE OF WHITE SUCKER	EMBRYONIC STAGE OF LONGNOSE SUCKER
0 (4 hr)	cleavage - 2-4 cells	cleavage - 2-4 cells
1	morula - >75 cells*	morula - >75 cells*
2	morula - many celled heaped dome	morula - blastodisc hemispherical
3	morula - blastodisc hemispherical	late epiboly - germ ring spreads to form head mesoderm and axial strand*
4	epiboly - blastodisc spreads over yolk*	animal pole - head mesoderm and axial strand develop
5	animal pole - head mesoderm and axial strand develop	organogenesis - rudimentary brain, optic vessicles, somites*
6	organogenesis - rudimentary brain, optic vessicles*	tail bud - eyes have lenses, somites prominent
7	somites - brain and optic vessicle proliferate	optic vessicles - brain partitioned, heart pulsating, movement in embryo*

...continued

Table 1. continued.

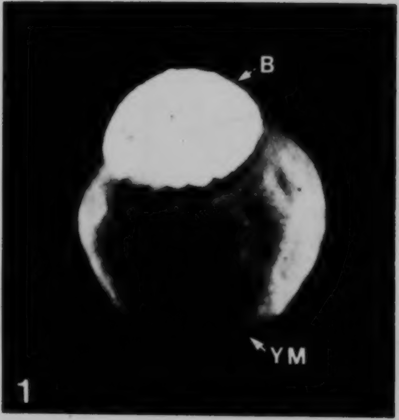
DAY OF INCUBATION	EMBRYONIC STAGE OF WHITE SUCKER	EMBRYONIC STAGE OF LONGNOSE SUCKER
8	tail bud - eyes have lenses, somites prominent, heart pulsating*	yolk irregular - yolk bulbous anterior and fusiform along trunk
9	optic vessicles - brain partitioned, movement in embryo	eyed - eyes pigmented, strong heart beat
10	yolk irregular - yolk bulbous anterior and fusiform along trunk	tail fin fold - pectoral ridges, olfactory placodes*
11	ventricles of brain - brain enlarged, fin fold on tail bud*	embryo active - blood pigmented
12	embryo active - blood pigmented	pectoral fin buds - mandibular and branchial segments
13	blood flow - tail enlarged	pigmentation - eyes deeply pigmented, melanophores on trunk
14	eyed - eyes pigmented, mandibular and branchial segments*	initial hatching - pectoral fin and olfactory placode well developed

...continued

Table 1. concluded.

DAY OF INCUBATION	EMBRYONIC STAGE OF WHITE SUCKER	EMBRYONIC STAGE OF LONGNOSE SUCKER
15	initial hatching - pectoral fin bud and olfactory placode, eyes darker, melanophores on trunk	hatching - yolk sac elongate, fin rays on unlobed tail, pectoral fins disc shaped*
16	hatching - yolk sac elongate, fin rays on unlobed tail, pectoral fins disc shaped	

Plate 1. Embryological stages of the white sucker. (1) Day 1 = 24 hr (19x), (2) Day 4 (17x), (3) Day 6 (23x), (4) Day 8 (26x), (5) Day 11 (24x), (6) Day 14 (22x). Legend: B = blastodisc; FF = fin fold; GR= germ ring; LE = lens of the eye; RB = rudimentary brain; TB = tail bud; OTV = otic vessicle; OV = optic vessicle; VB = ventricle of brain; YM = yolk mass; YP = yolk plug.



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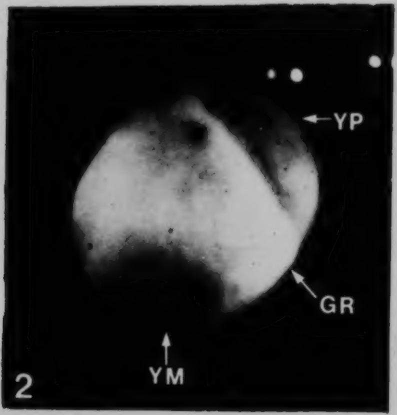

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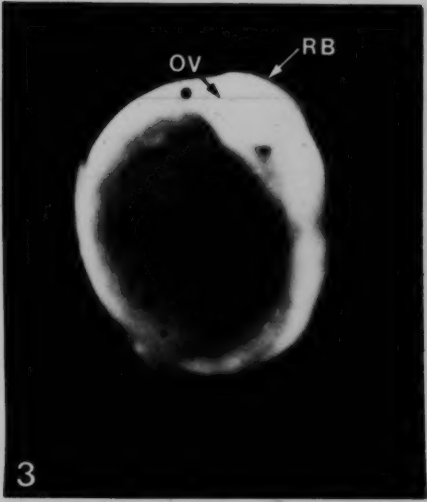

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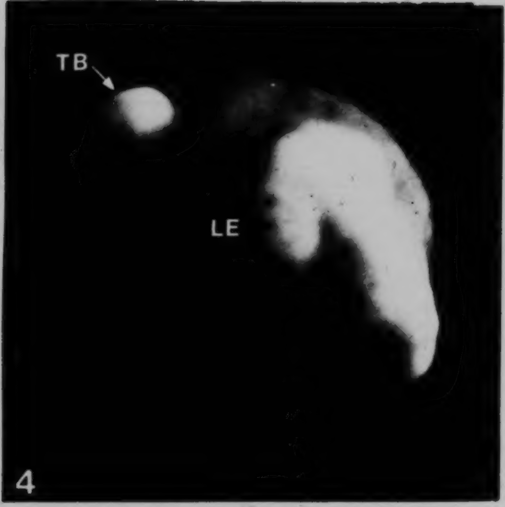

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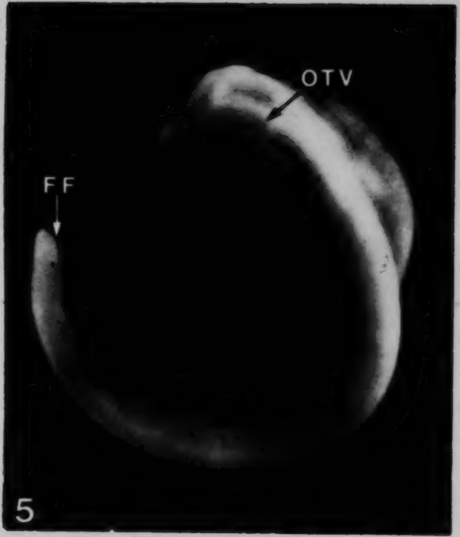

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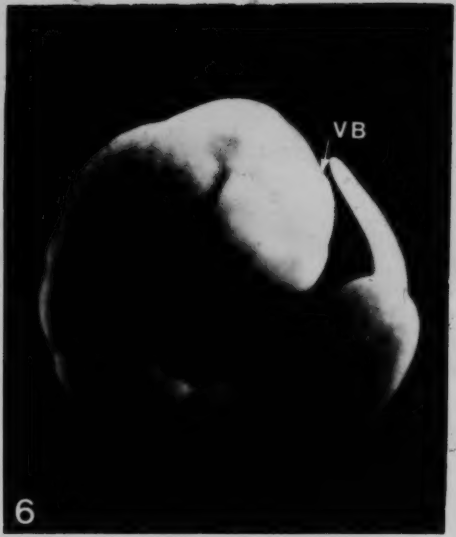

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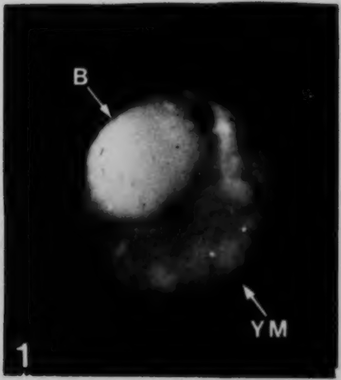
Plate 2. Embryological stages of the longnose sucker. (1) Day 1 = 24 hr (15x), (2) Day 4 (19x), (3) Day 5 (7x), (4) Day 7 (22x), (5) Day 10 (23x), (6) Day 15 (20x). Legend: B = blastodisc; FF= fin fold; GS = gill slits; HM = head mesoderm; LE = lens of the eye; M = mouth; N = nostril; RB = rudimentary brain; TB = tail bud; PAS = posterior of axial strand; PF = pectoral fin; PS = pericardial sac; OV = optic vessicle; VB = ventricle of the brain; YM = yolk mass.



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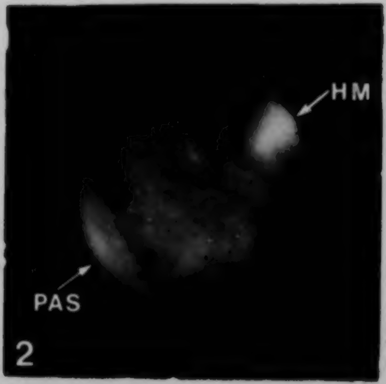

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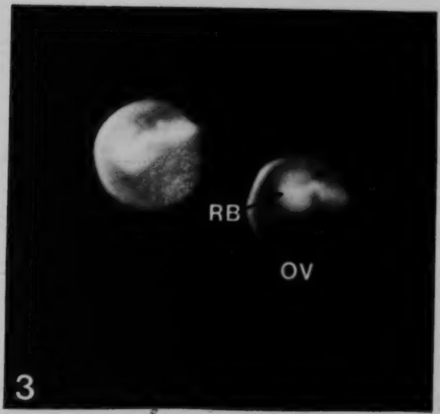

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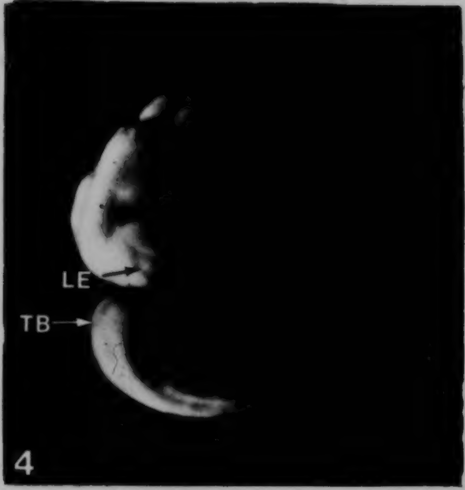

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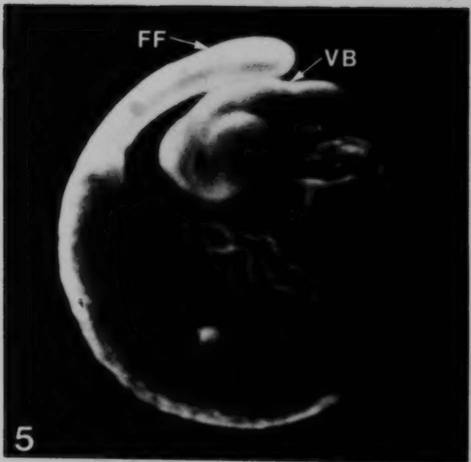

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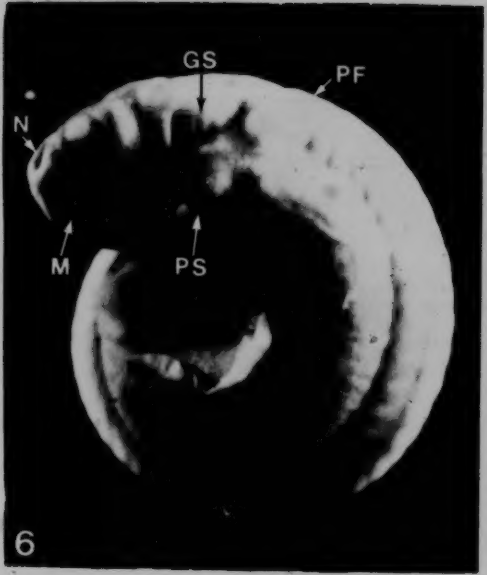

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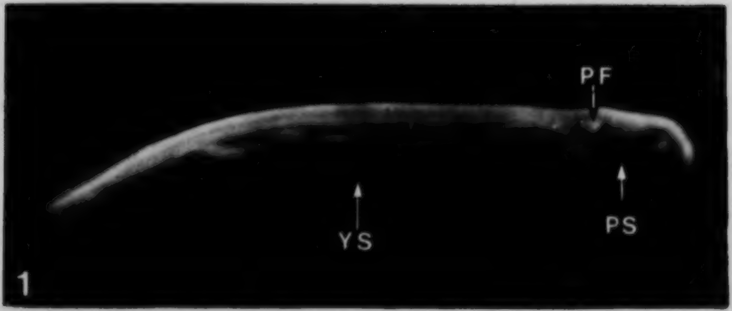
quite supple a couple of days prior to hatching, at which time some embryos were capable of rupturing the corion with their tails.

All larvae emerged tail first and remained on the bottom writhing to free themselves of their egg cases. White suckers had a body length of 9.2±0.12 mm (n=10) and longnose suckers were 8.1±0.5 mm (n=10) long. Larval longnose suckers were fixed before they had completely emerged from their egg cases. As a result, larvae were curled up and difficult to measure which probably accounted for their overall shorter length. Although larvae were extremely active after hatching they were incapable of swimming; probably because the swim bladder was not functional, the yolk sac was still relatively large, and the fins were basically undeveloped. About four days after hatching, larvae of both species still had elongate yolk sacs that measured approximately three quarters of the total body length (Plate 3.3). When larvae emerged from the gravel they had disc shaped pectoral fins, rays on the caudal fin, and usually four longitudinal rows of grey melanophores (Plate 3.3).

The only apparent difference in the embryological development of both species was that the circulatory system

Plate 3. Post hatch white suckers - days from fertilization. (1) Day 20 (11x), (2) Day 20 (11x), (3) Day 27 (10x). Legend: C = cloaca; M = melanophores; MO = mouth; PF = pectoral fin; PS = pericardial sac; RYS = remnant yolk sac; YS = yolk sac.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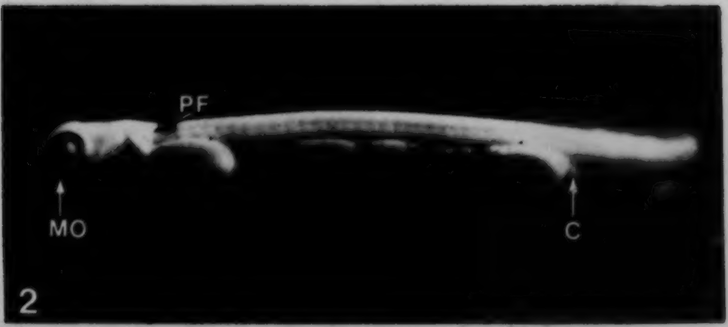
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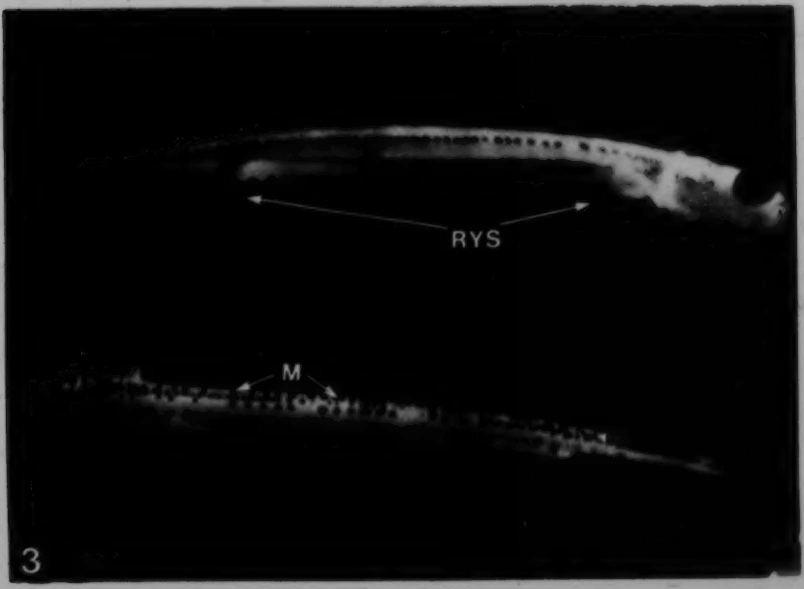
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took longer to develop in longnose suckers. Morphological differences in larvae involved the intensity of pigmentation in the eye. Upon hatching the eyes of white suckers were not as darkly pigmented as those of longnose suckers. However, in a couple of days after hatching the eye pigment in both species was comparable.

Attempts at raising sucker larvae in field aquaria were unsuccessful but white suckers were hatched and reared in laboratory tanks (Plate 3). After 27 days from fertilization (11 days post hatch) the yolk sac was almost totally absorbed and the suckers were nearing the post larval stage. Larvae (fry) at this stage were 11.8±.13 mm (n=10) long and able to swim. Most of the fish stayed above the mid-water line in the tanks but had to swim continually to avoid sinking. The swim bladder was presumably semi-functional at this time.

Downstream Movement of Fry

Sucker fry were first observed in Willow Creek on 17 June. Some fry had probably emerged from the gravel prior to this time since spawning occurred as early as 17 May. By 28 June, sucker fry were noted along the creek in most of the shallows and backwaters. Downstream movement of fry began in early June and continued until the first week in August (Fig. 2). Most fry moved or drifted downstream during a one month period from 25 June to 25 July.

There was no detectable morphological difference between white and longnose suckers captured in drift nets: hence all fry were considered at the genus level (i.e., *Catostomus* spp.). Owing to the predominance of adult white suckers (at least 10 white suckers to 1 longnose sucker) in the spawning run and the rarely observed spawning of longnose suckers, at least 90% of the drifting larvae were likely white suckers.

The mean size of fry caught in drift nets was 12.02±.93 mm (n=1351). There was a small but significant decrease in the length of fry from June to August (Table 2). This reduction in size was thought to be a result of more early larval suckers being captured later in the summer. There was no significant difference ($p>0.05$) in the sizes of larvae caught in midstream upper and lower nets, even though over twice as many fish were caught in the upper drift net (Fig. 2). The mean lengths of fry caught in upper and lower nets were 12.00 and 12.03 mm respectively. Sucker

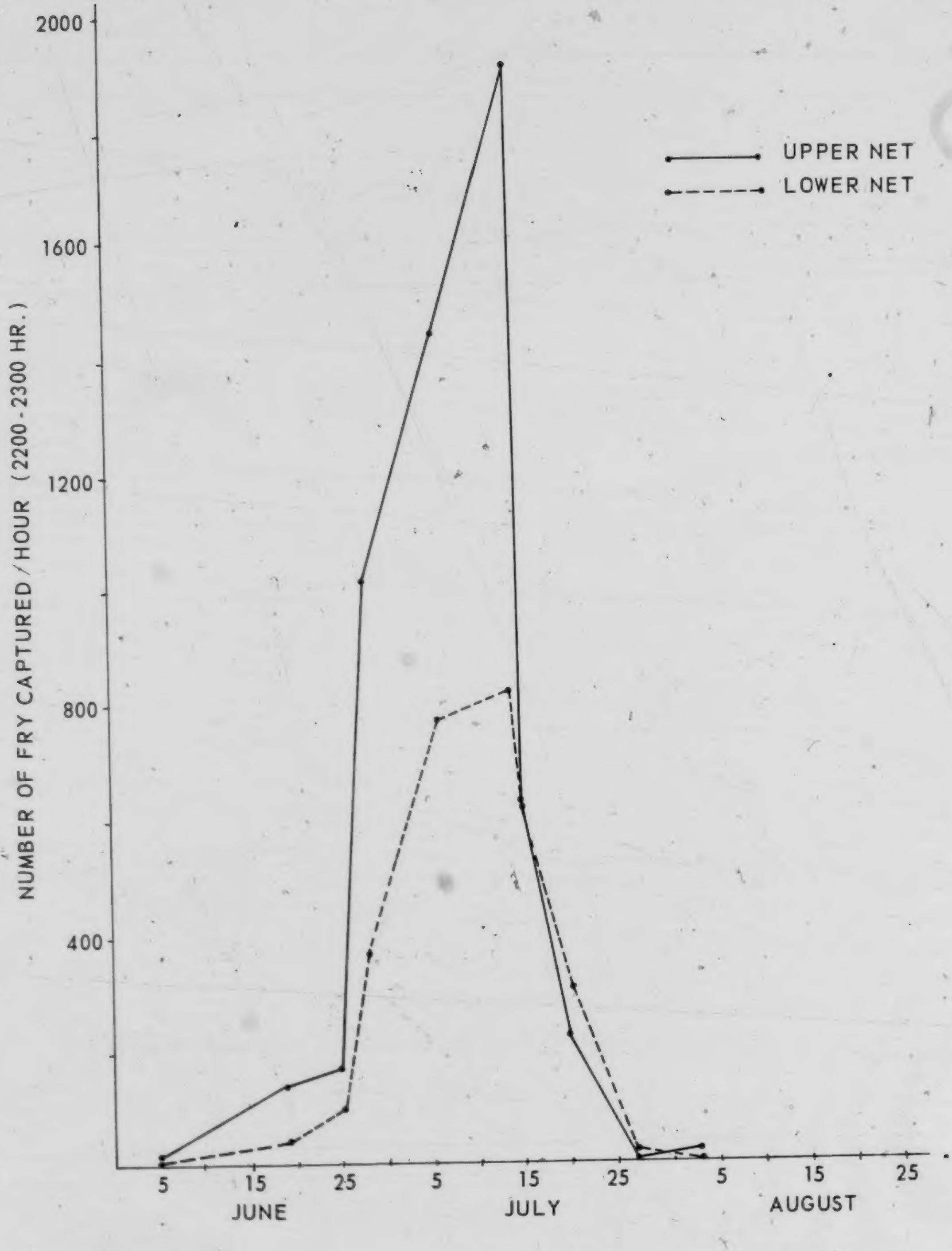

Figure 2. Seasonal drift of sucker fry based on captures from midstream upper and lower nets.

Table 2. Mean lengths (mm) of sucker fry sampled from all drift nets each month. S.E. = standard error, N = sample size, >> = significant difference ($p<0.05$) between months.

	JUNE		JULY		AUGUST
$\bar{x}$	12.15		11.72		11.21
S.E.	0.03	>>	0.06	>>	0.14
N	951		372		28

fry generally began moving downstream when they were around 11-12 mm in length. Based on laboratory experiments, these fry were 27 days from fertilization or 12 days post hatch. There was no significant difference ($p > 0.05$) in the lengths of 12 day old larvae (reared in the lab) and those fry caught in drift nets.

Diel movement was examined on four occasions (Fig. 3). With the exception of 25-26 June, peak movement occurred from 2200-2300 hrs, and most movement took place during the dark hours. A snow fall on 24 June and rain on 25 June created an unusual situation with regard to drift. Discharge slowly climbed, beginning at 0800 hr, at a rate of about 0.03 m^3/sec per hour: the water also became more turbid. From 1500-1600 hr the discharge jumped from 1.8 m^3/sec to 2.0 m^3/sec and gradually receded at about 0.3 m^3/sec per hour after 1800 hr. This probably explained the mid day peak in drift which occurred between 1500-1600 hr on 25 June. The reduced nocturnal drift rate on 25-26 June may have been a result of the relatively low water temperature or the increase in turbidity. The only other remarkable instance in the drift study took place on 28 June. At 1400-1500 hrs there was a peak in downstream movement that could not be attributed to an increase in flow. In fact, discharge decreased almost 0.002 m^3/sec from 1400-1500 hr.

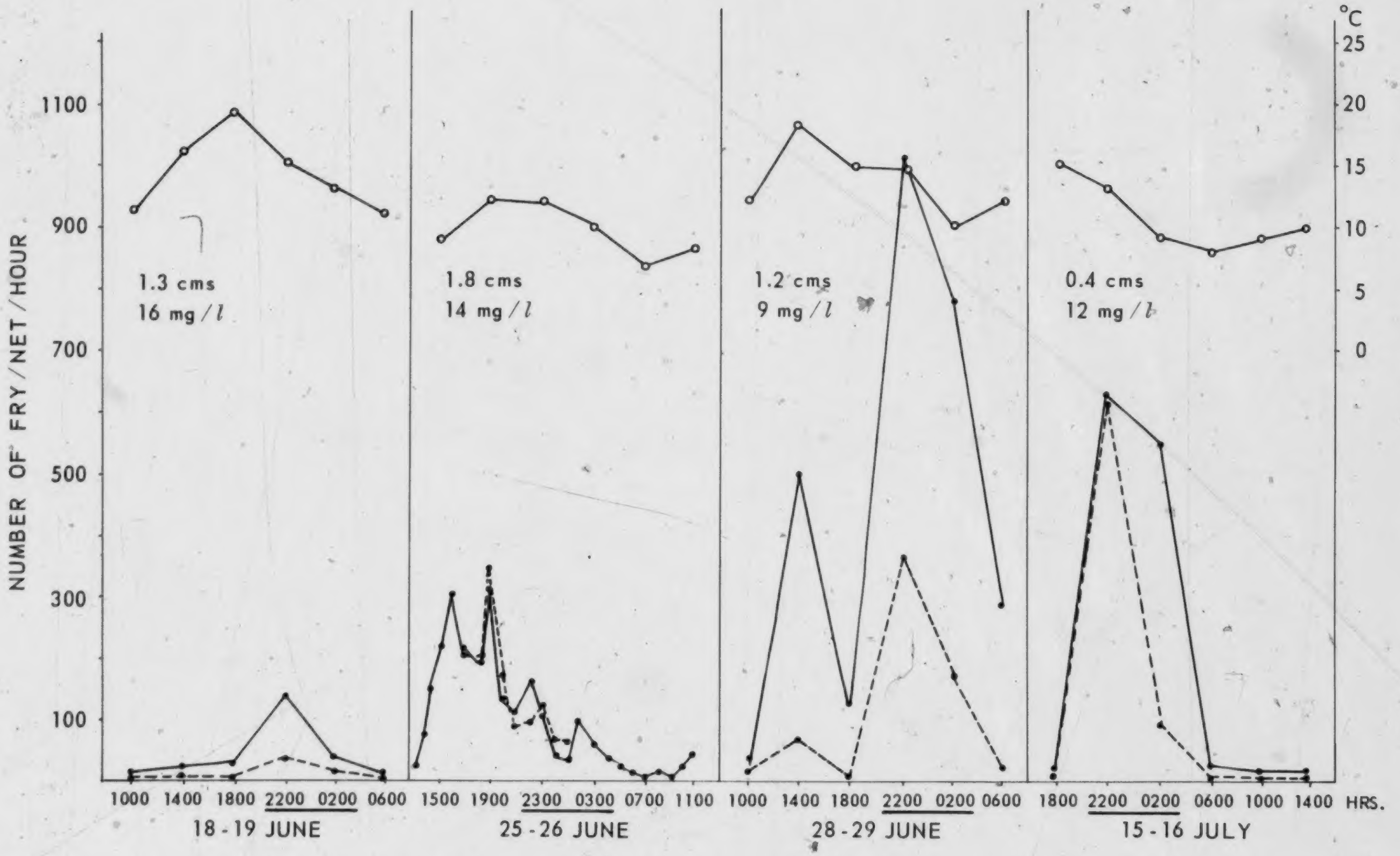

Figure 3. Diel movement of sucker fry. Horizontal black bars indicate dark hours.

During all four diel drift experiments the sky was cloudless and on 18 June there was bright moon light. This nocturnal illumination, however, did not seem to subdue drift of sucker fry during the dark hours. Variation in water temperature was significantly correlated ($r=.81$, $p<0.05$) with fry captures on 25-26 June. Nonsignificant r values on the other three occasions negated any trend in the association between water temperature and drift.

Diel and seasonal drift data indicated that most sucker fry moved downstream in the upper part of the water column (Figs. 2 and 3). The lower net rarely caught more fish than the upper net. When four nets were used, the greatest number of fry were captured in the south bank net which was situated in the fastest water (Table 3). Fewer fry were captured in the mid-stream nets and the fewest were taken in the north bank net which was located in the slowest water. In general, the greatest disparity between the captures in north and south bank nets occurred when discharge was low (Table 3). The south bank net also caught more fry than the midstream upper net when discharge dropped. There was no significant difference ($p>0.05$) in the lengths of fry caught in the north and south bank nets. Differences in total captures on eight occasions

Table 3. Sucker fry captures from four nets placed in the stream from 2200-2300 hr. Discharge (cms) and level of suspended sediment (mg/l) are also given. NB = north bank, MU = midstream upper, ML = midstream lower, SB = south bank.

DATE	NB	ML	MU	SB	Σ	cms	mg/l
June 18	61	41	144	67	313	1.27	16
June 28	459	363	1012	233	2067	1.22	9
July 6	224	778	1445	190	2637	0.68	8
July 14	109	825	1910	4707	7551	0.42	17
July 15	33	621	628	1672	2954	0.40	12
July 20	52	302	225	518	1097	0.25	14
July 27	1	12	5	22	40	0.17	34
Aug. 3	3	8	20	1	32	0.54	11
Σ	942	2950	5389	7410	16,691		

appears to be a function of time (i.e., age of larvae) rather than a result of the variation in discharge or turbidity.

DISCUSSION

There was no observable difference in the mating behaviour of white and longnose suckers, although the latter were only observed spawning on two occasions. Sexual dimorphism, apparent in both species, was most striking in longnose suckers. Male longnose suckers had a brilliant crimson lateral band while male white suckers were differentiated from females by a dark black lateral stripe under a cream coloured occipital band. Spawning white suckers in Willow Creek were not coloured but Reighard (1920) and Bond (1972) have reported males to possess a rosy lateral tinge during the spawning season.

Males of both species were smaller than females and had nuptual tubercles. The role of these secondary sex structures is not fully understood. Nikolsky (1963) contends that "nuptual dress" is a natural stimulus to egg laying in cyprinids. Reighard (1920) postulated that tubercles on male white suckers are used to grasp the female during the spawning act. Considering the difference in size between the sexes it is unlikely that tubercles would suffice to restrain the much larger female, particularly since tubercles are most well developed on the posterior fins. A more plausible explanation for the utility of tubercles would be in sexual recognition. Prior to the spawning act males frequently approached the female from the rear, and in doing so males could visually recognize a female by an absence of tubercles on the anal and caudal fins. After the initial approach of several males, the spawning act commenced with all fish in the group moving their tails in a slow side to side motion. In this instance, the roughened tubercles could provide a tactile stimulus by contacting the female in the region of the anal and caudal fins. Tubercles, therefore, may function both as visual and tactile stimuli in mating. The importance of the tactile stimulus would be manifested in turbid waters. Nuptual tubercles are probably important only during the breeding season because they are shed shortly after spawning is finished.

Suckers spawned on silt free gravel riffles that were exposed to a good current. Since no nest was prepared, eggs, adhesive after fertilization, presumably drifted a short distance before settling to the bottom near the tail of the riffle. Fertilized eggs in such a location likely had the best chances of survival because they were exposed to a constant flow of clean water. A perpetual supply of oxygen rich water is important to successful embryological development (Phillips 1971). Furthermore, a good current probably aids in transporting newly emerged larvae downstream to an environment with a suitable food source. This is important since emerging larvae have little yolk material left and must begin feeding (mainly on plankton) within a few days (Crawford 1923; Stewart 1926).

The embryological development of white and longnose suckers was comparable; although, eggs from both species could not be incubated at the same time. Longnose suckers incubated at 12.2°C hatched one day earlier than white suckers incubated at 10.0°C. The higher mean temperature during the longnose sucker incubation period likely caused embryos to hatch earlier. Higher temperatures influenced embryological development within the first three days. By day 3, longnose sucker embryos were at a more advanced stage of development than 3 day old white suckers. Embryological development in both species is accelerated by increasing temperature. Raney and Webster (1942) incubated white sucker eggs at temperatures ranging from 4°C to 21°C. Eggs hatched in 14 days at 4°C, whereas eggs incubated at 21°C hatched in only 4 days; although, mortality was high in the latter case. Geen (1958) reported incubation times of 11 and 8 days for longnose sucker eggs reared at 10°C and 15°C respectively.

Incubating embryos collected from spawning grounds can provide an estimate of the time when spawning took place. This is helpful when spawning is not readily observed. Major stages in embryological development useful in determining the approximate age of larvae incubated under spring spawning conditions are: (1) morula, 2-3 days, (2) start of organogenesis, 5-6 days, (3) tail bud, 6-8 days, (4) eyed, 9-14 days, (5) active embryo (prehatching) 15-16 days. The rate of embryological development depends on temperature (Long and Ballard 1976), and incubation time appears to vary between different sucker populations. The incubation periods of white sucker eggs raised at about 10°C (temperature used in this study) have been reported as follows: 7 days at 10°C (Raney and Webster 1942), 8 days at 11°C (Geen *et al.* 1966), 11 days at 14°C (Bassett 1957), 19 days at 10°C (Long and Ballard 1976), and 21 days at 10°C (Long and Ballard 1976), and 21 days at 10°C (Stewart 1926). Geen (1958) and Geen *et al.* (1966) found the incubation period of longnose suckers to be 11 days at 10°C. In general the incubation period of white and longnose suckers is about two weeks.

White and longnose suckers reared in incubation trays were morphologically inseparable. Geen *et al.* (1966) felt that white suckers were large (12-14 mm) and had concaveshaped heads while longnose suckers were smaller (10-12 mm) and had a convex surface of the head. This present study provided no evidence that would confirm the findings of Geen *et al.* (1966). Furthermore, fry caught in drift nets were virtually all 11-12 mm in length: discrete modes were not evident.

Larval suckers remained in the gravel for 11 or 12 days after hatching and emerged about 27 days after fertilization. These periods compare well with those reported by Geen *et al.* (1966) of a two week gravel stage followed by emergence one month after spawning. A couple of factors may be responsible for inducing emergence. Firstly, larvae have little yolk material remaining when they leave the gravel. Secondly, the swim bladder begins to inflate around two weeks post hatch (Long and Ballard 1976). Increased buoyancy coupled with a need for food could provide the impetus for larval emergence.

Young suckers started descending Willow Creek about 27 days after fertilization. At this stage, fry were 12 mm long and able to swim, but the pectoral and caudal fins were small. Fish of this size were not capable of holding a stationary position in the current which resulted in displacement downstream. Whether this movement is active or passive is a matter of debate. Larvae emerging from the gravel must do so in an active fashion. Once out of the gravel post larvae (fry) actively maintain their position in the upper part of the water column. Clifford (1972) felt that small newly emerged sucker fry (12 mm) were passively transported downstream whereas larger fry (28 mm) actively moved downstream.

Seasonal drift net capture data from Willow Creek tend to support Clifford's (1972) conclusions. Sucker fry were caught moving downstream from June to early August. These fry had a mean length of 12.02 mm and fish larger than 14 mm were presumably capable of maintaining a fixed position in the current since none were captured in drift nets. If larger fry had been captured in drift nets, particularly in quiet water, this might indicate that young suckers were actively moving downstream. Based on this evidence it would seem that sucker fry "drift" downstream. Larger fry (28 mm), of the size captured by Clifford (1972) in the Bigoray River, were not caught in drift nets in Willow Creek. This may be attributed to the difference in stream flow, Willow Creek being a tumbling mountain stream and the Bigoray River a sluggish muskeg stream. It was assumed that most fry were flushed out of Willow Creek when they emerged although a small percentage did remain in the stream.

Drifting sucker fry were nearer the surface than the bottom as also documented by Clifford (1972) and Gale and Mohr (1978). This difference in position in the water column was not related to size since fry from upper and lower nets were not significantly different ($p>0.05$) in length. Greater numbers of fry were probably captured in the upper drift net because the swim bladder inflates about the time larvae emerge and begin drifting and this positive buoyancy would tend to bring more fry to the surface. Those fry caught near bottom may have only had partially inflated swim bladders or they may have been forced downward by turbulent water. Gale and Mohr (1978) recovered virtually all sucker fry near the surface. The near absence of young fish on bottom was probably related to the nature of the river. The channel was 350 m wide, 2.3 m deep, and probably lacked turbulent water necessary to force fry into deeper water. Fry taken from drift nets in Willow Creek also tended to swim near the surface in aquaria. This corresponds with the beginning of the top swimming phase proposed by Stewart (1926) and discussed by Bond (1972).

Most sucker fry drifted at night. Small mid-day peaks in discharge did cause some increases in day time movement but most peaks occurred just after dusk. Nocturnal drift has been reported by Bond (1972), Clifford (1972), Geen (1958) and Geen *et al*. (1966). Sucker fry apparently react to light like young salmonids that have been noted to lose their rheotactic ability when light intensity is diminished (Hoar 1953; Northcote 1962). Increases in stream flow and turbidity also increase drift rate (Geen *et al*. 1966). Furthermore, they found when a gas lantern was suspended over a drift net at night fewer fry were captured. Apparently fry either hid in the gravel or were able to visually orient themselves and maintain a position in the current.

The most important abiotic factor governing movement of fry is light. Variations in discharge and turbidity may have some influence on drift rate but temperature is not involved. Geen *et al*. (1966) suggested that fewer fry drift during moon lit nights. At Willow Creek, illumination by the moon did not seem to subdue nocturnal drift. Presumably, drifting fry are disoriented and float downstream like inanimate pieces of detritus, etc. Gale and Mohr (1978), in postulating the ecological significance of this night movement felt that drifting fry, disoriented at night and looking like debris in the water, would be less susceptible to predation than fry that were oriented in the current in a "fish like" manner. This night active behaviour is not restricted to the fry of suckers. Adults and probably juveniles are night active (Campbell 1971) showing discrete inshore and instream movements at night (Spoor and Schloemer 1938). Suckers are forage species and it is possible that nocturnal activity evolved as a result of selective pressure from predation.

Sucker fry drifted down Willow Creek during a two month period. The rate of downstream movement was related to the age of larvae, and not to differences in temperature, discharge, or turbidity: albeit temperature can influence embryological development. Larval suckers generally did not emerge from the gravel until they were about 12 days old. Apparently, larvae emerge about the 12th day irregardless of stream flow, temperature, or turbidity. Certainly, spates would flush more larvae out of the gravel, but normally the larvae must be old enough before they will emerge. This explains the highest drift rates occurring when the water was relatively low and clear. There was also less mixing of the water at low levels which reduced the captures in slower water. By and large, most fry moved downstream in the fastest water.

With the information obtained in this study it is possible to construct a chronology of the spawning and early life history of suckers in Willow Creek. Upstream movement of adults and seasonal drift of fry are relatively easy to quantify, but frequency of spawning activity and hatching are not as easy to document on their own. Therefore, seasonal drift data and incubation times can be used to estimate spawning and hatching dates by back calculating from fry drift data (Fig. 4). The rates of spawning and hatching are depicted by dotted lines (Fig. 4) because both are approximated from drift data.

Spawning did not begin in earnest until upstream movement had subsided in June. It was estimated, from observations on the lower [illegible]00 m of the creek, that spawning peaked between 27 May and 7 June. These dates preceded the peak in Figure 4 which may have been a result of spawning occurring later in upper reaches. As spawning tapered off hatching became more frequent. The peaks in spawning and hatching were 16 days apart. Fry began moving early in June and the drift rate peaked on 15 July. This peak was 12 days after peak hatching. Drift rate dropped abruptly in late July and most fry had moved out of Willow Creek by August. Virtually all larval suckers were at the post larval stage by early August. This provided the young suckers with at least three months of open water to continue feeding and growing.

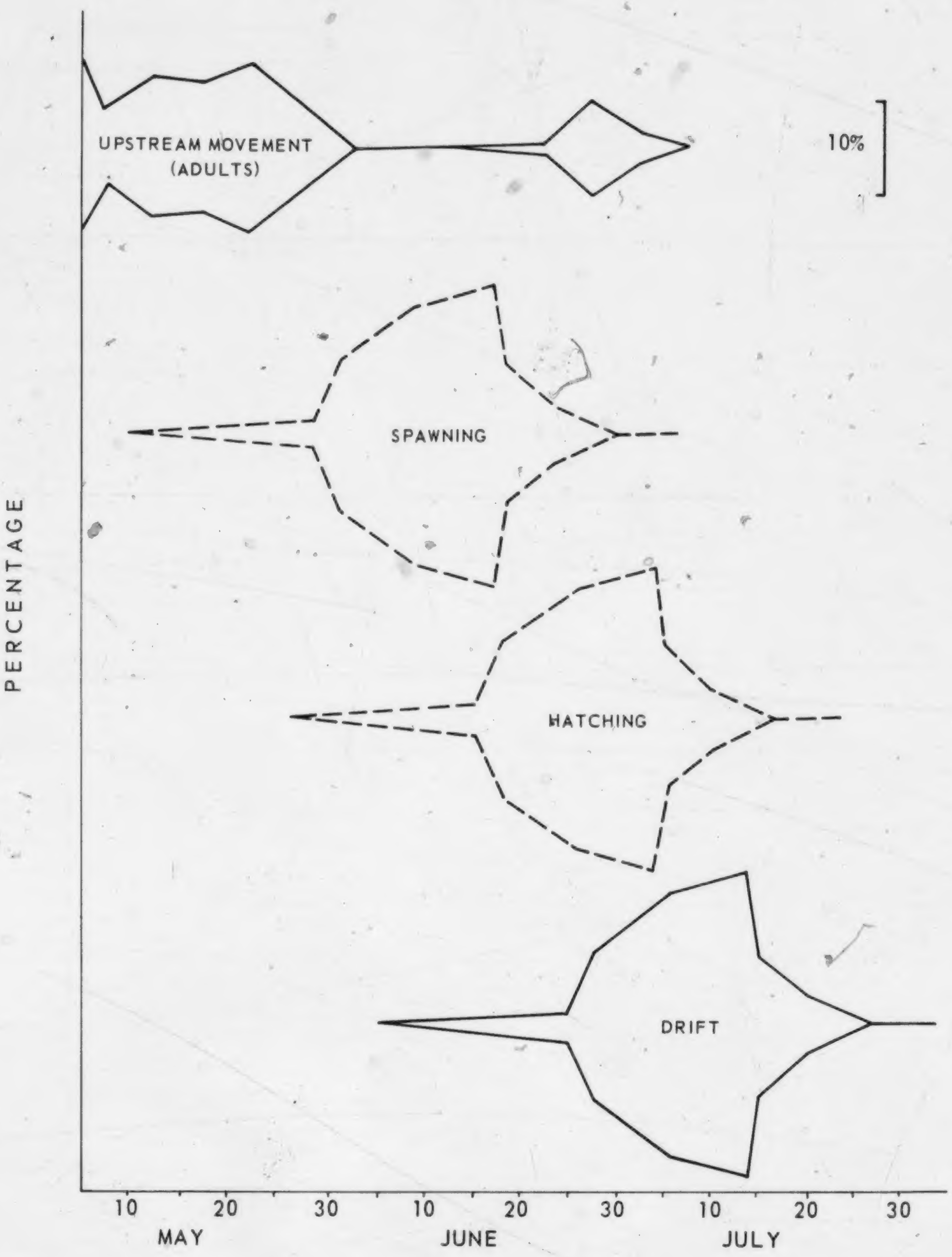

Figure 4. Chronology of adult movement, spawning, hatching, and downstream movement of fry.

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CHAPTER III Age and growth of white suckers, *Catostomus commersoni*, and longnose suckers, *C. catostomus*, in the Willow Creek-Chain Lakes system, Alberta.

ABSTRACT

Age and growth of white suckers, *Catostomus commersoni*, and longnose suckers, *C. catostomus*, from the Willow Creek-Chain Lakes system, Alberta, were examined. Cross-sectioned pectoral fin rays were useful for determining age and growth rates by back calculation. Males and females grew at a similar rate until sexual maturity was reached at the ages of V and VI. Females grew larger and lived longer than males. The maximum ages of white suckers and longnose suckers were X and VIII years respectively; however, fish older than VI years were rare. Length-weight regression equations for both species are as follows:

white suckers

$$\log W = -5.0181 + 3.0331 \log FL$$

longnose suckers

$$\log W = -4.9426 + 2.9947 \log FL$$

White suckers were slow growing relative to other populations, but longnose suckers were not. Although food habits were not examined, differences in growth rates may be attributed to inter specific differences in the diet.

INTRODUCTION

Populations of white suckers, *Catostomus commersoni*, and longnose suckers, *C. catostomus*, exhibit wide variations in growth rates throughout North America. Beamish (1973) classified white sucker populations in Ontario as fast growing and others as slow growing. He also questioned the validity of using scales for age determination. Beamish and Harvey (1969) found that annular marks on pectoral fin rays of white suckers were more reliable than annuli on scales, and that the scale method tended to under estimate the true ages of suckers after maturity. In virtually all past studies dealing with age and growth of suckers scales have been used for age determination (Bailey 1969; Brown and Graham 1953; Coble 1967; Dence 1948; Geen 1958; Harris 1962; Raney and Webster 1942; Rawson 1951; Stewart 1926; Spoor 1938). Otoliths have seldom been used except to verify scale age determination (Bond 1972). After examining a number of bony parts from white suckers, Ostler (1975) felt that cross sectioned pectoral fin rays were best for age determination and back calculations.

The purpose of this study was to examine the growth patterns of white and longnose suckers using pectoral fin rays for age determination and back calculation. The growth rates of suckers in the Willow Creek-Chain Lakes system was of interest, because reservoir environments vary more from year to year than natural lakes (Benson 1971). This in turn can impair the growth rates of fish living in impoundments (Elrod and Hassler 1971). Growth data from this study were compared with those from previous studies.

STUDY AREA

The study area is 90 km south of Calgary, in the east slope of the Rocky Mountains of Alberta. Field studies were carried out on Chain Lakes Reservoir and Willow Creek above the impoundment (lat. 50° 11' 47" N, long. 114° 12' 46" W). The creek is typical of many east slope streams. The reservoir is long (10 km) and narrow (<1 km) with a surface area of 389 ha. Maximum depth is 9.0 m, and mean depth is 5.3 m. Mid summer water temperatures exceed 16°C on bottom. The creek and reservoir are ice covered each year from about November to April. Water chemistry data from the creek are in Appendix 1.

Water is released from the reservoir, primarily during the spring, over a spillway at the south end of the impoundment. The spillway is a partial barrier to fish emigrating from the system, and this structure likely blocks all upstream movement into the reservoir.

The most abundant large fish species in the reservoir are as follows: white suckers, longnose suckers, mountain whitefish (*Prosopium williamsoni*), and rainbow trout (*Salmo gairdneri*). Rainbow trout are stocked annually and represent the bulk of the angler harvest.

MATERIALS AND METHODS

Field investigations were carried out from 9 March to 17 June 1976. Fish were collected from the reservoir with beach seines and standard gang gillnets. The gillnet gangs consisted of eight 15.24 m x 2.44 m monofilament nets and one 91.44 m x 2.44 m multifilament nylon net. The stretched mesh sizes of the monofilament nets were, 2.54 cm, 3.81 cm, 5.08 cm, 6.35 cm, 7.62 cm, 8.89 cm, 10.16 cm, and 11.43 cm: the nylon multifilament net was 10.16 cm stretched mesh. Fish were collected from the creek with beach seines, a backpack electroshocker (Smith Root MK VII), and upstream, and downstream traps at two separate fences. The lower fence was 600 m from the mouth of the creek and the upper fence was 16.4 km from the mouth. Both fences were a modification of the trap described by Shetter (1938).

All fish were sampled in a routine manner. Sex, maturity, length, and weight were recorded. A scale sample and one pectoral fin were taken from each fish. Scales were removed from the left side below the dorsal fin and above the lateral line.

At least four scales from each sample were mounted between acetate slides for reading. The first four to six fin rays from each fin were cross sectioned near the base, and two or three 1 mm thick sections were placed in glycerine on a microscope slide for viewing. Smaller fins were imbedded in fiber glass resin prior to sectioning. Scales and fin ray sections were viewed with a binocular dissecting scope using direct and reflected light. Scale ages were determined as discussed by Lagler (1956), and fin ray ages were interpreted from Beamish (1973). All fin ray sections were read at least twice: scales were used primarily for verification of ages determined from fin ray sections.

Measurements for back calculations were taken from the anterior half of the first fin ray along the ventral axis. All fin sections were measured with an ocular micrometer at a magnification of 50x. Prior to back calculation, 100 fin ray sections from longnose suckers were measured to determine the relationship of body length to fin ray radius. Body length data were grouped into 2.0 cm size classes from 28 cm to 40 cm as described by Le Cren (1947). Mean fork lengths and fin ray radii from each size classes were then used in a regression equation:

$$FL=a+b\ RR$$

where FL is fork length (mm) and RR is ray radius x 50. The values of a and b were both constants derived from the grouped data. The correction factor (b) from the above equation was then used in the following equation (Lagler 1956):

$$FL_1=\frac{RR_1(RR_2-b)}{FL_2}+b$$

FL_1 = fork length at a particular annulus
RR_1 = ray radius at a corresponding annulus
FL_2 = fork length at capture
RR_2 = ray radius at capture

A total of 745 white suckers and 197 longnose suckers were sampled for age and growth analyses. Length-weight relationships were determined from logarithmically transformed length and weight data. The following regression equation was used to describe length-weight relationships:

$$\log W=a+b\log FL$$

W = body weight
FL = fork length
a = constant (y intercept)
b = constant (slope)

RESULTS

White Suckers

Age

Fin ray annuli appeared as dark rings under direct light and light rings under reflected light. Annuli were distinctly different from growth bands. The focus was considered as the first annulus and the edge of the fin ray was considered as the last annulus. New growth was not evident around the periphery of the fin rays. Scales from larger fish were difficult to interpret because peripheral annuli were crowded and not easily identifiable.

White suckers ranged in age from I to X years and females lived longer than males (Fig. 1). All of the I year old fish and most of the II, III, and IV year olds were captured from the reservoir since few subadults (immature fish) were present in the creek.

Scales were generally best for determining ages of small fish for the following reasons: (1) small fins were difficult to section; and (2) annuli were quite distinct on scales from younger fish. Fins from fish under 90 mm

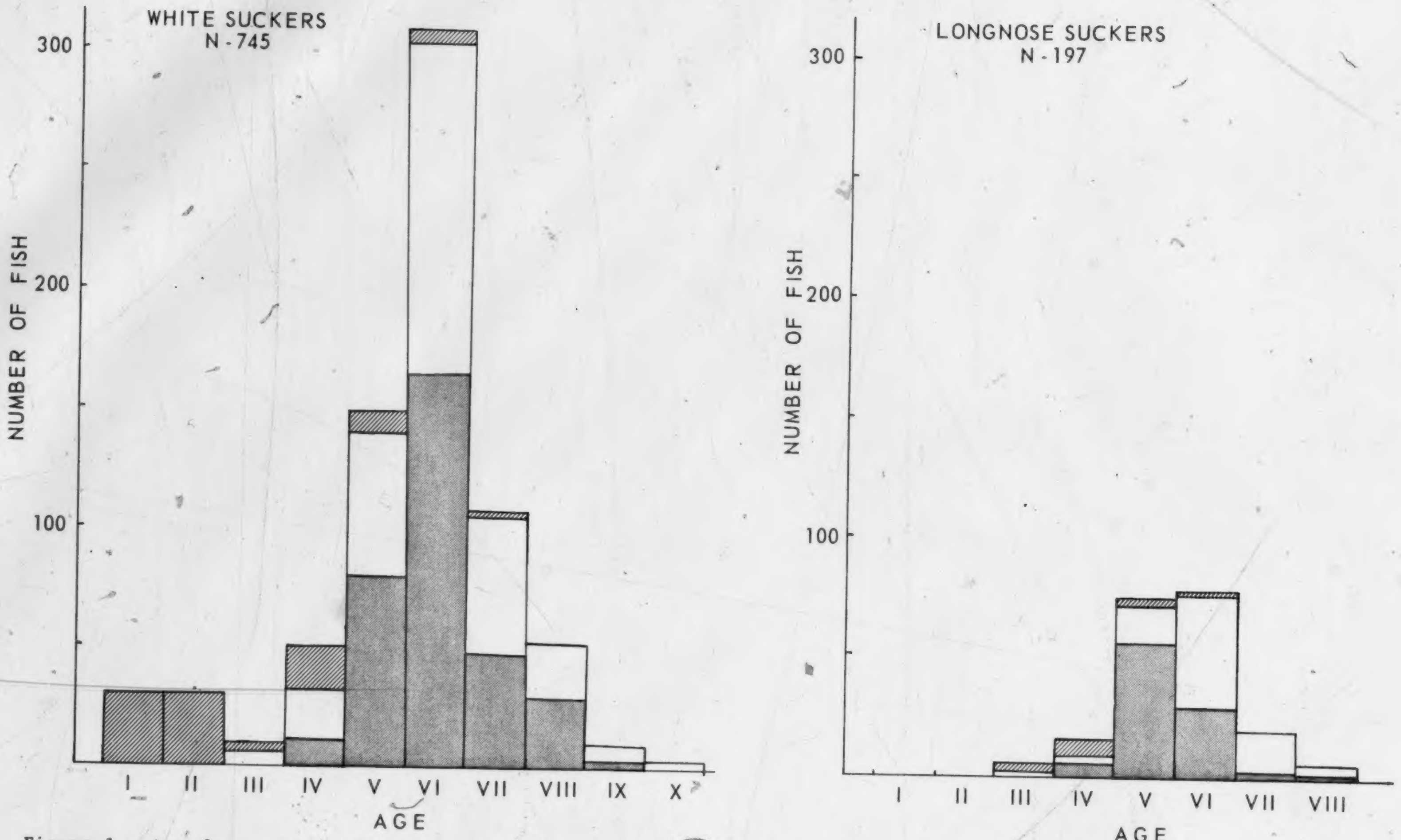

Figure 1. Age frequencies of male (stippled bars), female (open bars), and immature (cross hatched bars) white and longnose suckers sampled for age and growth analyses.

(II year olds) were not suitable for sectioning. Back calculations were not done on white suckers because younger age classes were adequately represented.

Growth

The length and weight curves of white suckers showed inflexions at age V (Figs. 2 and 3). Females after the age of IV were significantly larger than males (Table 1). White suckers grew relatively fast up to age V when most fish, particularly males, spawned for the first time (Chapter I). After maturity, annual increments in length and weight were around 20 mm and 100 g respectively.

The plotted mean fork lengths and mean weights at each age exhibit the characteristic allometric growth curve (Fig. 4). Logarithmic transformation of both variables gave a linear relationship. The length-weight relationship for white suckers can be expressed as:

$$\log W = -5.0181 + 3.0331 \log FL$$

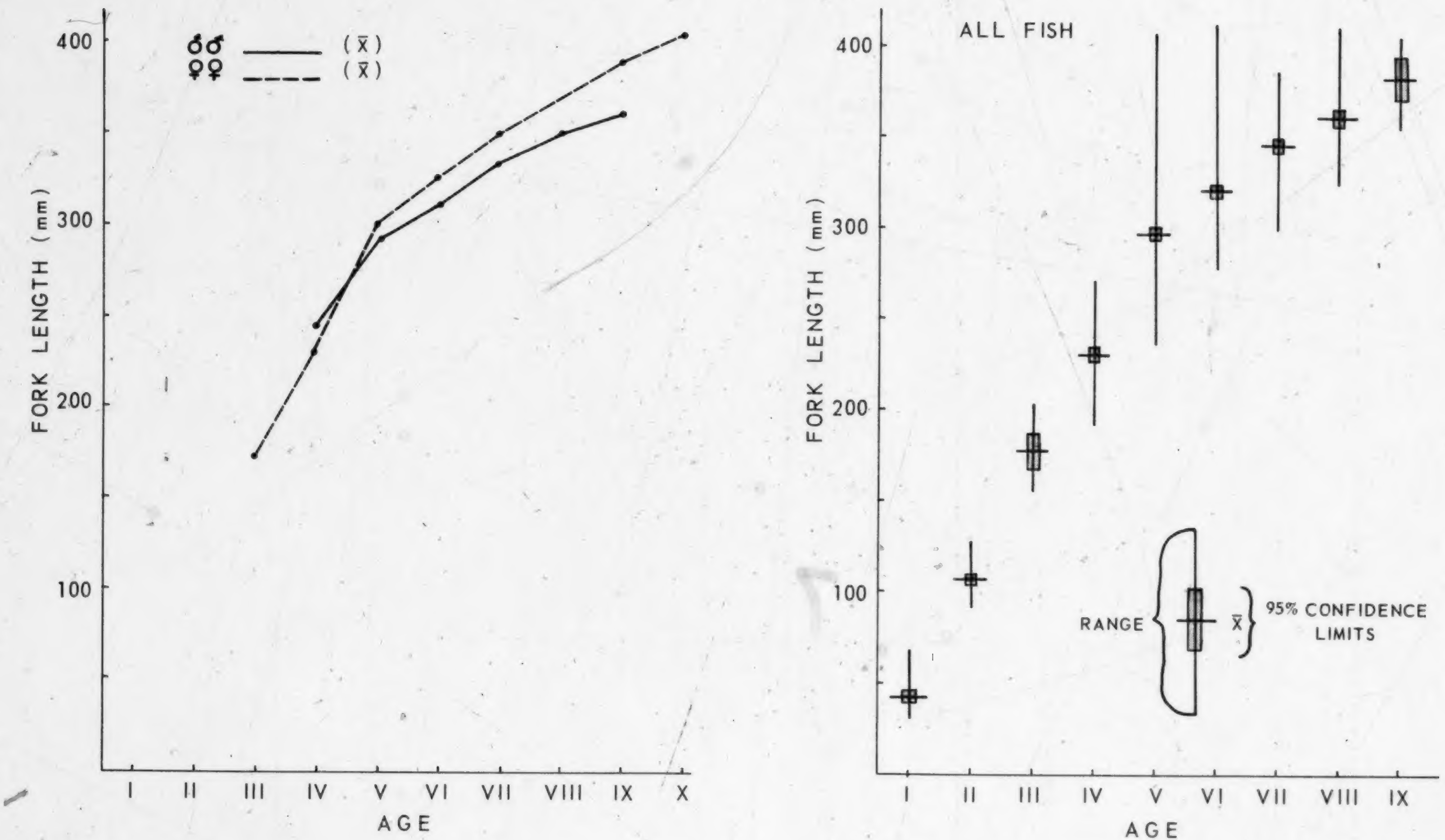

Figure 2. Age-length curve of white suckers.

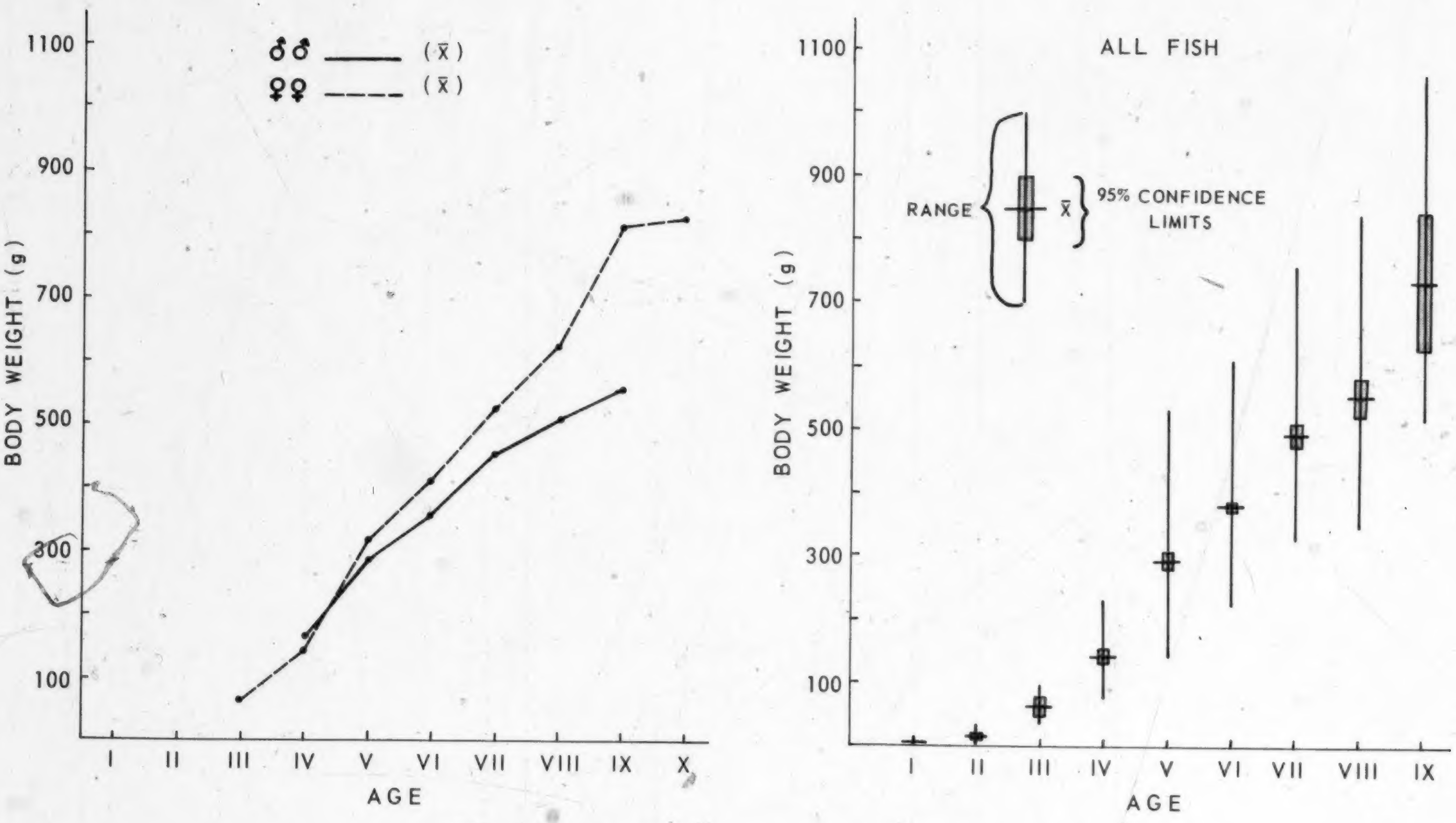

Figure 3. Age-weight curve of white suckers.

Table 1. Student t-test values (length and weight) of male versus female white suckers and male versus female longnose suckers at each age. * = females significantly larger, $p < 0.05$.

WHITE SUCKERS			LONGNOSE SUCKERS		
AGE	LENGTH	WEIGHT	AGE	LENGTH	WEIGHT
4	1.99	1.44	4	0.03	1.42
5	3.12*	2.77*	5	2.45*	3.42*
6	8.12*	7.07*	6	7.05*	8.12*
7	4.21*	4.17*	7	.868	1.17
8	4.62*	4.31*	8	7.00*	4.16*

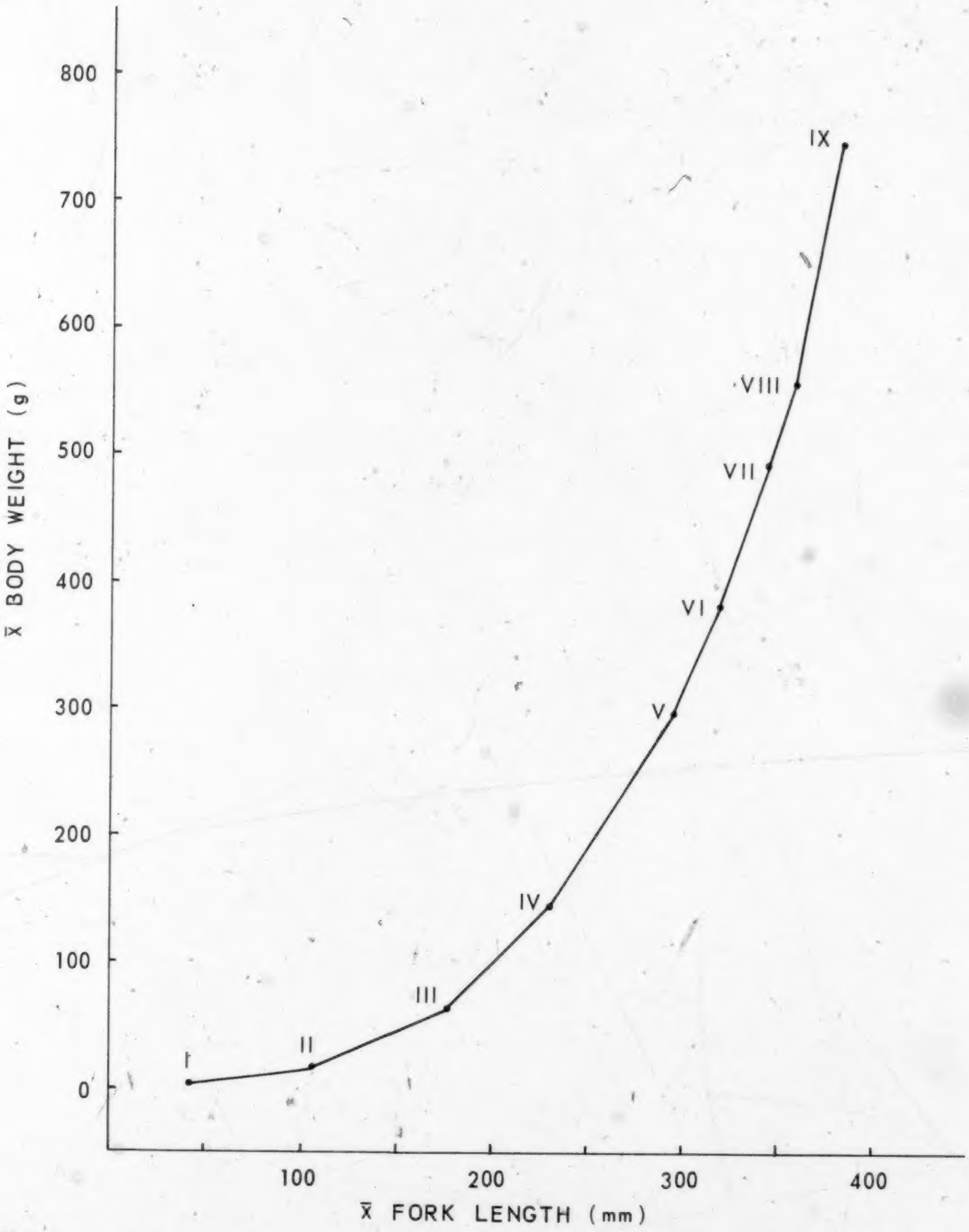

Figure 4. Length-weight curve of white suckers. Roman numerals indicate ages.

The value of the slope indicates that white suckers increase in weight at a rate slightly greater than the theoretical cubic relationship ($W=nL^3$) explained by Lagler (1956).

Longnose Suckers

Age

Fin ray cross sections from longnose suckers were comparable to those of white suckers. The focus was designated as the first annulus. The periphery of the fin ray was considered to be the last annulus, since new growth was not evident. Peripheral annuli on scales were difficult to identify because of crowding.

Longnose suckers ranged in age from III to VIII years and females tended to dominate older age classes (Fig. 1). Back calculations were done owing to a lack of younger fish in the sample.

Growth

The fork length-finray radius relationship, necessary for back calculations, can be expressed as follows:

$$FL=30.69+4.27\ RR$$

The relationship of fork length to fin ray radius was linear. After age IV, females were larger than males (Fig. 5). Back calculated lengths were not statistically different ($P>0.05$) from empirical lengths so back calculated age groups I, II, and III were included with empirical data in the growth curve (Fig. 6).

Age-length and age-weight curves showed inflexions at age V (Figs. 6 and 7). Females were longer and heavier than males except at ages IV and VII (Table 1). A decline in the growth rate after the age of V was associated with the onset of sexual maturity. After the age of V, annual increments in length and weight were about 25 mm and 100 g respectively.

Mean fork lengths plotted against mean weights illustrate an allometric growth curve (Fig. 8). The length weight relationship of longnose suckers is as follows:

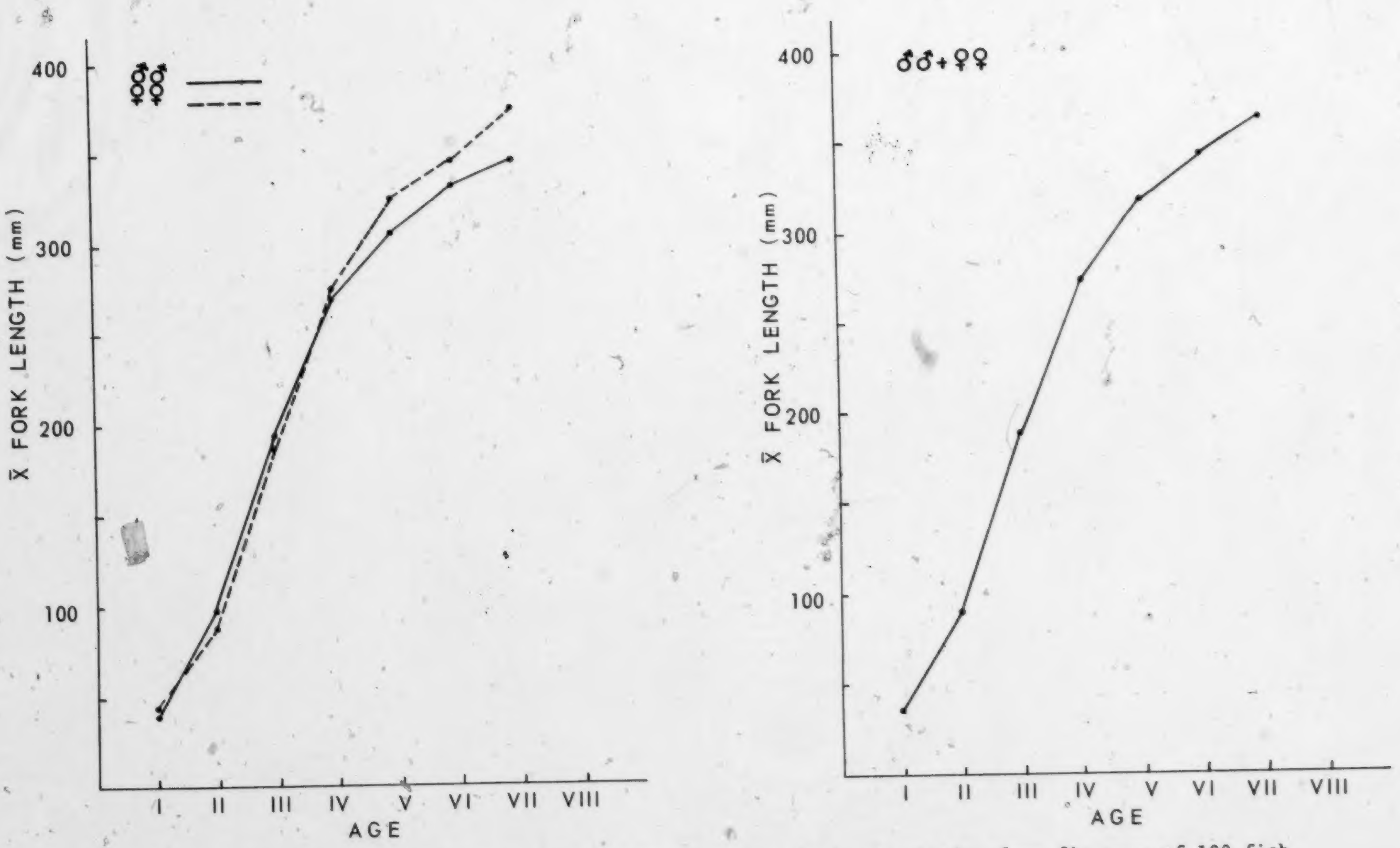

Figure 5. Age-length curve of longnose suckers based on back calculation from fin rays of 100 fish.

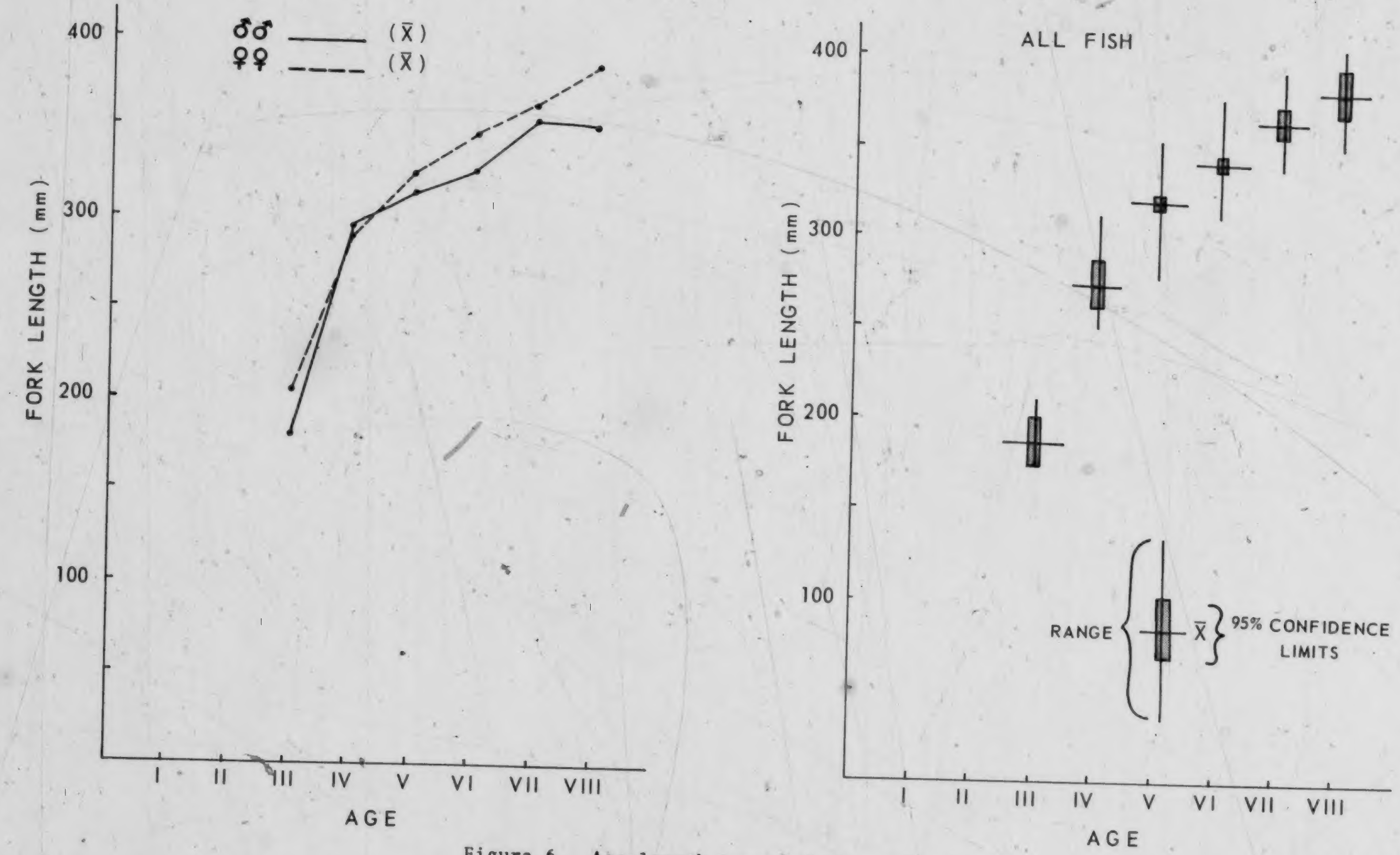

Figure 6. Age-length curve of longnose suckers.

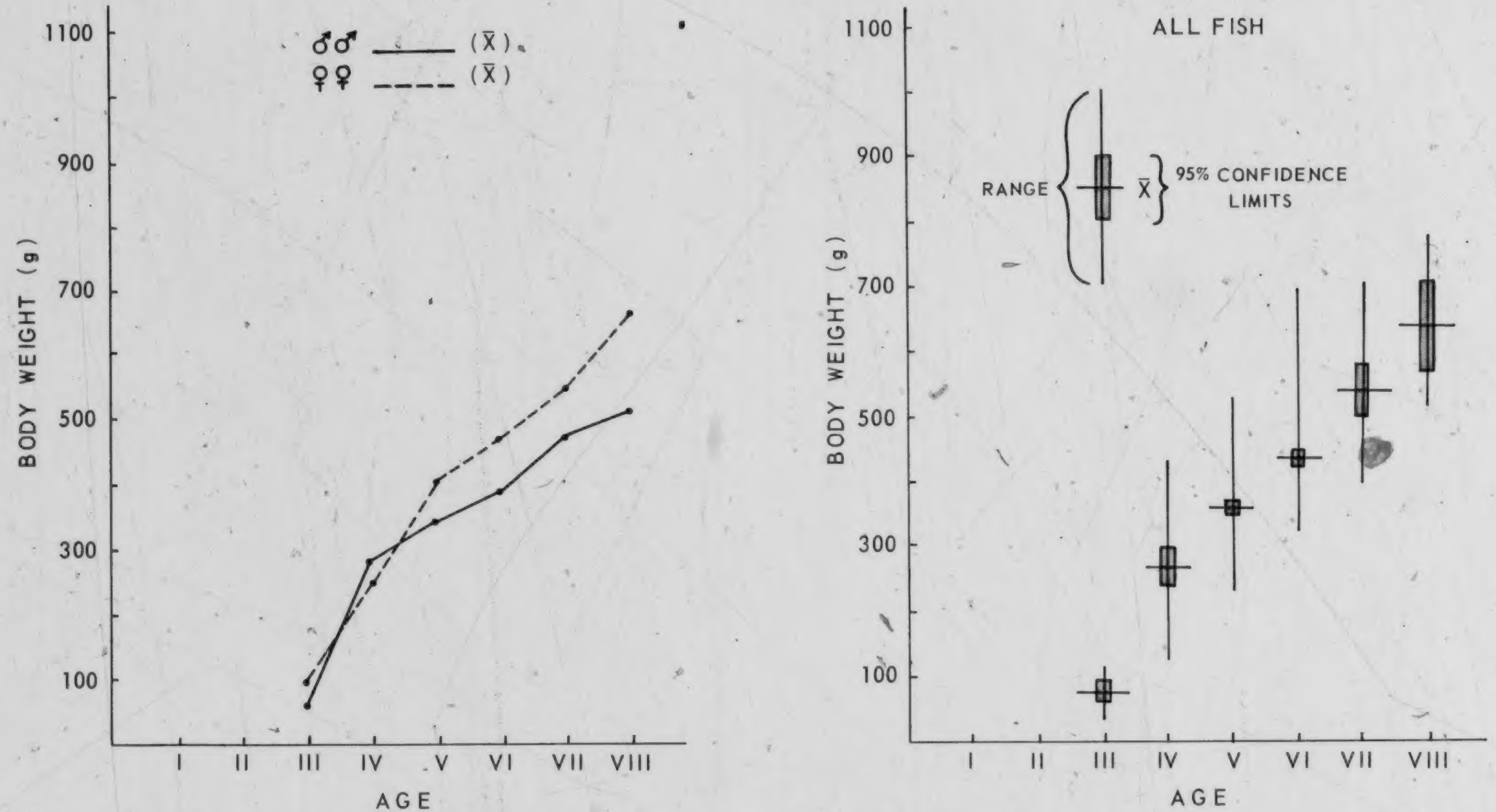

Figure 7. Age-weight curve of longnose suckers.

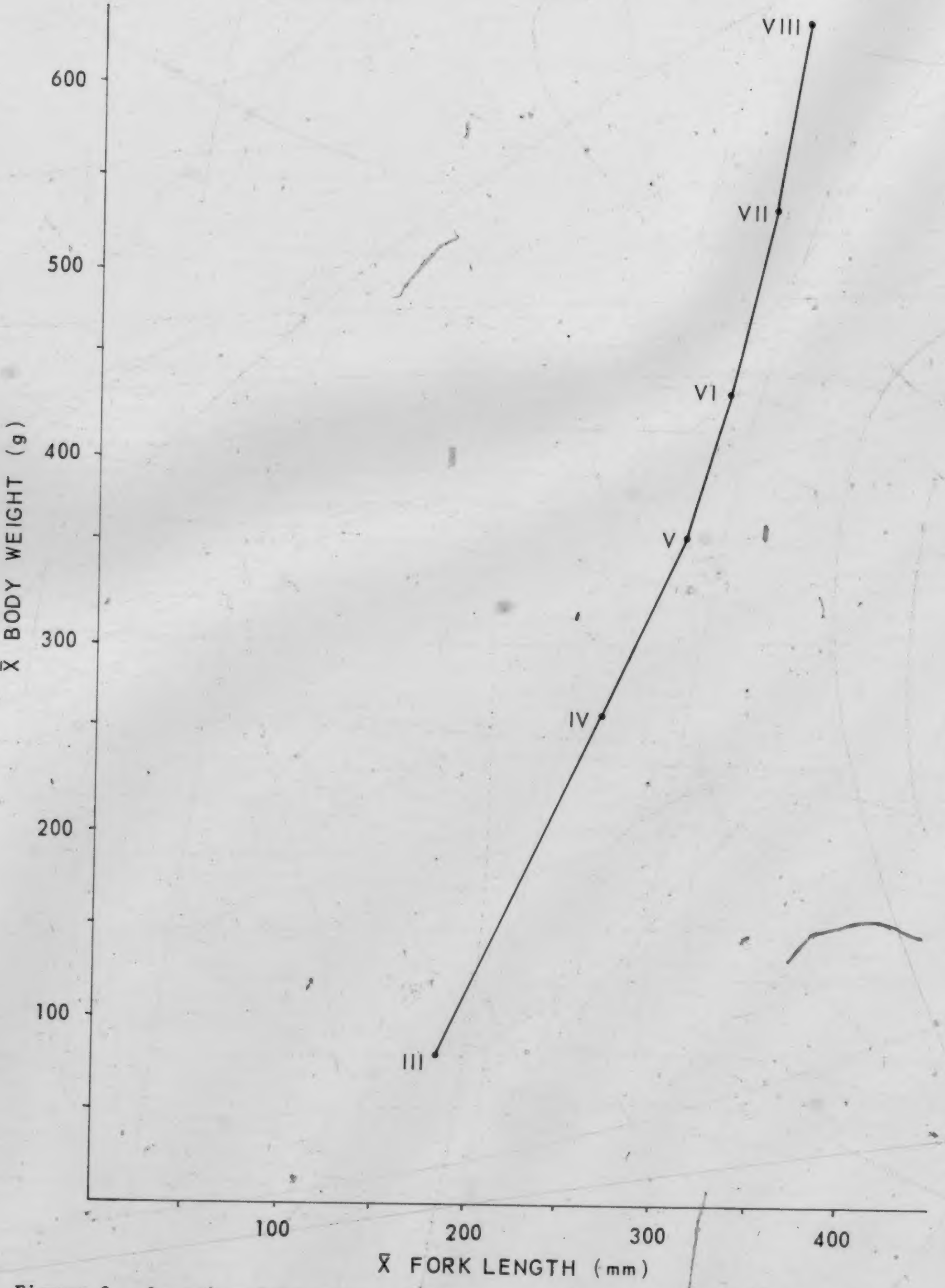

Figure 8. Length-weight curve of longnose suckers. Roman numerals indicate ages.

$$\log W = -4.9426 + 2.9947 \log FL$$

The value of the slope indicates that growth in weight is slightly less than the theoretical cubic relationship ($W=nL^3$) explained by Lagler (1956).

DISCUSSION

Growth studies on white and longnose suckers have relied mainly on scales for age determination. Some researchers have encountered difficulty using scales since annuli are not always discernable (Coble 1967; Dence 1948; Geen *et al*. 1966). Beamish and Harvey (1969), and Beamish (1973), found that age determination by the scale method tended to underestimate the true ages of suckers after maturity. These authors also felt that cross sectioned pectoral fin rays provided a more reliable estimate of age in suckers.

If scales are used for age determination and back calculation the following assumptions are generally made (Everhart *et al*. 1975):

(1) scales remain constant in number and identity
(2) scales growth is proportional to body growth
(3) annuli on scales must be formed every year

The last two assumptions are true of pectoral fin rays as well, but fin rays are not lost or damaged as readily as scales. Furthermore, the choice of "key" scales is important in back calculation since the measurement of different scales introduces error (Reiger 1959). This problem does not exist if fin rays are used, but precision and location of cut are important when cross sections are made.

Cross sectioned pectoral fin rays proved to be an efficient and reliable means for age determination of suckers. Annuli were distinct and easily discernable from growth bands, even near the periphery of the fin ray. Scales were useful in verifying the ages of small suckers, but annuli near the outer edges of scales from larger fish were difficult to separate. Fin rays were also better for back calculations because annuli were distinct, thus allowing better precision in measurement. Prior to back calculation one should measure fin ray radii along several axes. The axis that provides the best correlation of fin ray radius to body length should then be used for back calculation.

Cross sectioned pectoral fin rays of white and longnose suckers were comparable. Growth bands of both species were relatively broad up to the ages of V and VI when sexual maturity was first reached. An inflexion in age-length curves around the age of V for both species (Figs. 2 and 6) indicated a reduced growth rate after sexual maturity was reached. Most white and longnose suckers migrate into Willow Creek to spawn for the first time at ages V and VI (Chapter I). After fish had spawned for the first time, and gametic products were being produced each year, the growth rate gradually declined. Reduced growth rate was also apparent in fin rays as peripheral annuli were closer together.

Males and females exhibited different rates of growth after sexual maturity was reached. Females tended to grow larger and live longer than males. This situation exists in most other populations of white suckers (Bond 1972; Dence 1948; Geen 1958; and Spoor 1938) and longnose suckers (Bailey 1969; Brown and Graham 1953; Geen 1958; Harris 1962). Growth curves of males and females were combined for both species to allow a comparison with other populations (Figs. 9 and 10).

Populations of white suckers exhibit variable growth rates throughout their range (Fig. 9). Fast growing populations have been reported by Beamish (1973), Priegel (1976), and Raney and Webster (1942). Slow growing populations have been examined by Beamish and Crossman (1977), Dence (1948), and Spoor (1938). White suckers from the Willow Creek-Chain Lakes system are intermediate to slow growing, with similar growth curves to populations in Shadow Mountain Reservoir, Colorado (Hayes 1956) and the Bigoray

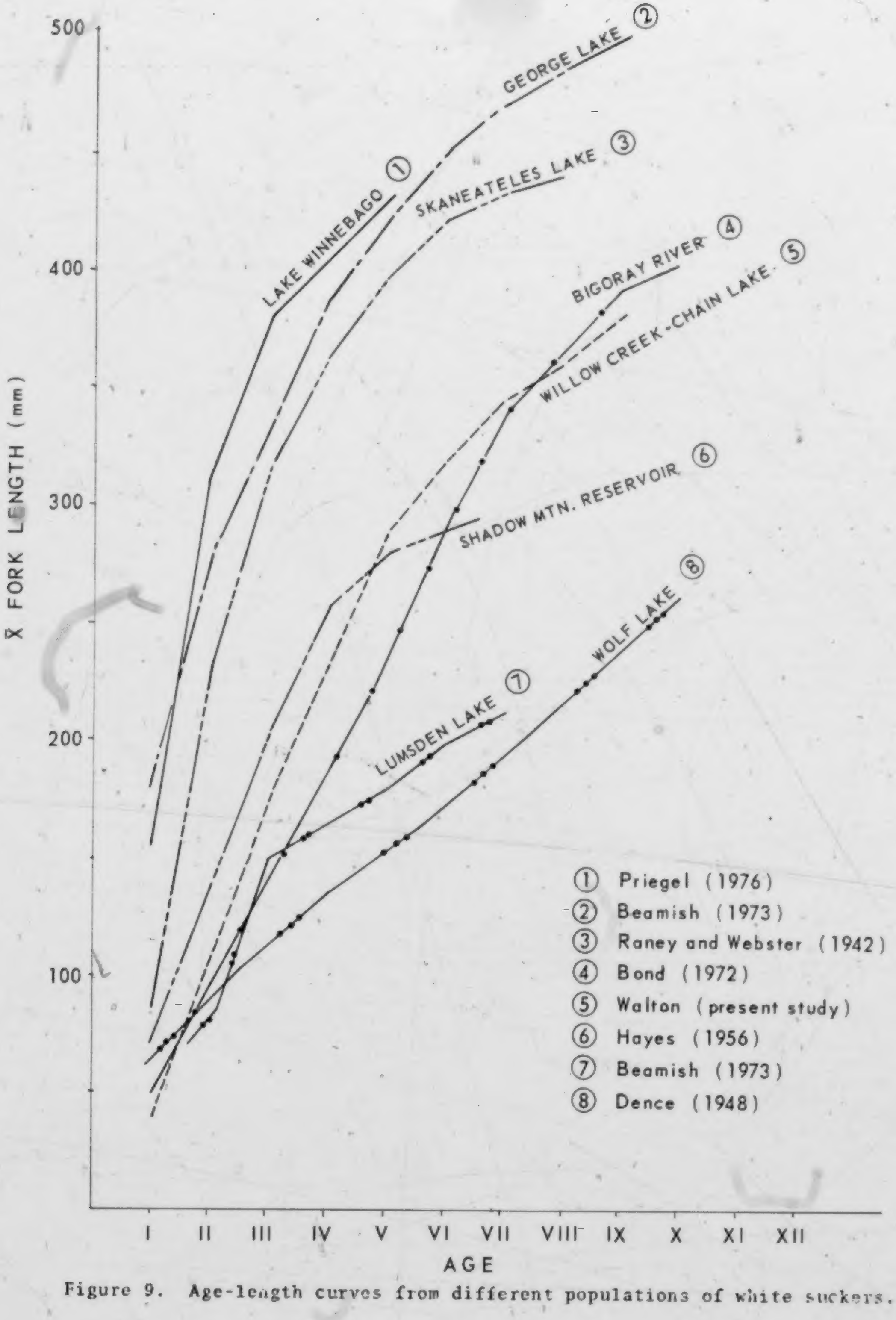

Figure 9. Age-length curves from different populations of white suckers.

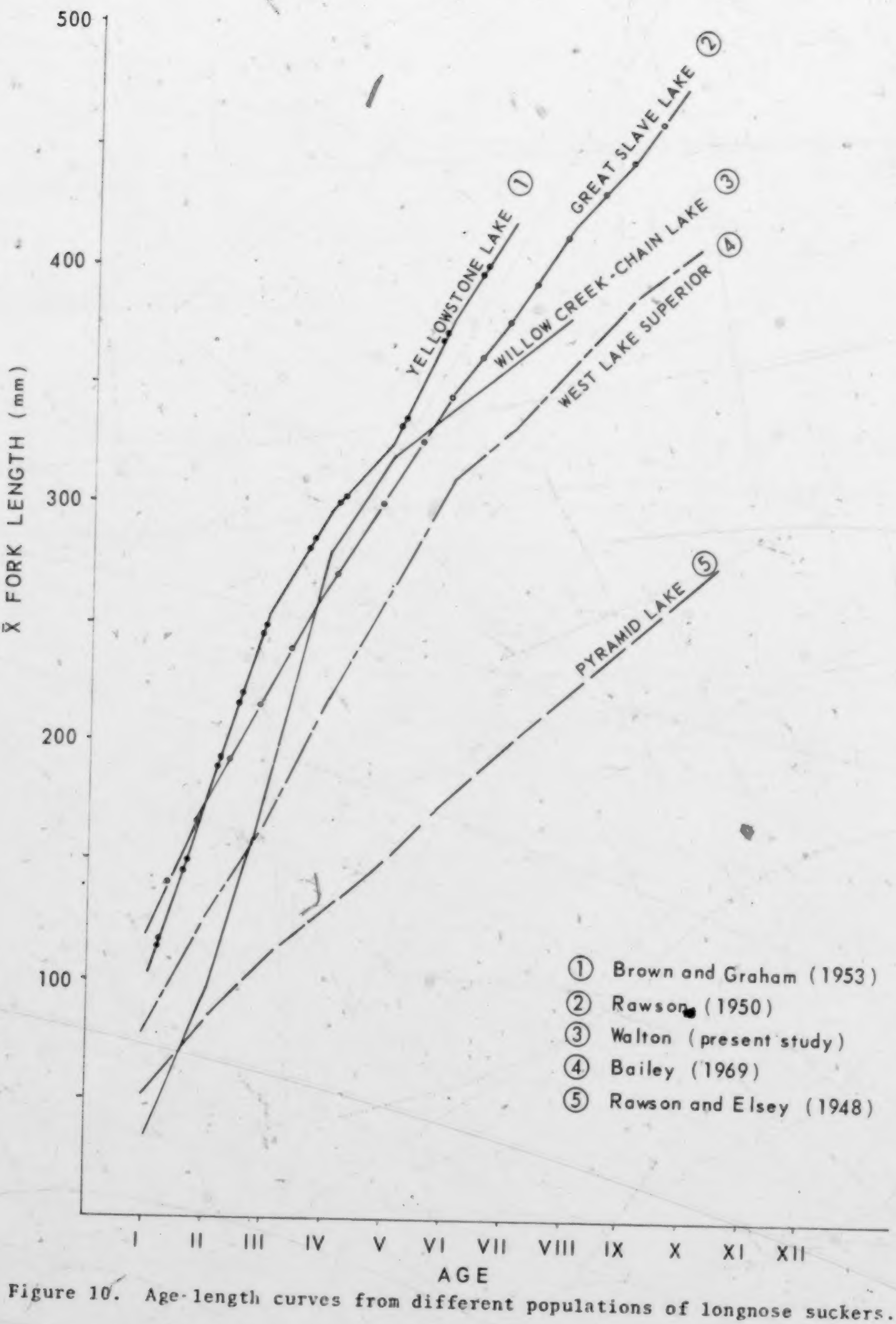

Figure 10. Age-length curves from different populations of longnose suckers.

River, Alberta (Bond 1972). Underlying reasons for slow growth rates have been cited as, environmental pressure (limited food and space), overpopulation (Beamish and Crossman 1977), and lake acidification (Beamish and Harvey 1972). Findings of Beamish and Tsuyuki (1971), provide some evidence for genetic differences between slow and fast growing populations of white suckers.

In Chain Lakes the growth rate of white suckers may be impaired by over population and sub-optimal habitat. Willow Creek provides good spawning habitat and spring runs of white suckers are large (Chapter I). White sucker fry are prone to predation by rainbow trout and mountain whitefish; but after the second year piscine predation appears to be infrequent (pers. obs.). Bidgood (1973) concluded that lack of predation in Pigeon Lake resulted in overpopulation and reduced size in lake whitefish (*Coregonus clupeaformis*).

Fluctuating water levels in reservoirs influence the productive littoral areas, and this in turn can impair growth rates in fish that inhabit impoundments (Elrod and Hasler 1971). White suckers in Shadow Mountain Reservoir had a comparable growth rate to those in Chain Lakes Reservoir (Fig. 9). The subdued growth rate of white suckers in the Willow Creek-Chain Lakes system may be a result of, overpopulation, intraspecific competition, and low productivity. These factors apparently do not have the same influence on the longnose suckers in the system since they exhibit a comparatively fast rate of growth (Fig. 10). This may indicate a lack of interspecific and intraspecific competition for food. Intraspecific competition is probably nonexistent because of the low density of longnose suckers in the system (Chapter I). However, there may be some interspecific competition in younger fish as both species are relatively small until their second and third years. An examination of the food habits of white and longnose suckers in Chain Lakes may aid in interpreting the growth rates of both species.

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CHAPTER IV Gonad development and fecundity of white suckers, *Catostomus commersoni*, and longnose suckers, *C. catostomus*, in the Willow Creek-Chain Lakes system, Alberta

ABSTRACT

Annual gonad development and fecundity of white suckers, *Catostomus commersoni*, and longnose suckers, *C. catostomus*, from the Willow Creek-Chain Lakes system, Alberta, were examined. White and longnose suckers had comparable annual reproductive cycles. In males, testes underwent rapid spermatogenesis during late summer, and by November spermatozoa appeared in the seminiferous tubules. Gametogenesis in the females lagged behind that of the males. Ovaries gained most of their weight before winter and oocytes developed gradually up to spawning time in May. Seasonal variations in the gonadosomatic index were indicative of cytological changes in the gonads.

Ovaries of white and longnose suckers were similar in histological appearance. Testes, on the other hand, showed one major difference: spermatozoa of white suckers were oval while those of longnose suckers were spherical.

Fecundities of both species were relatively low, a fact which may be attributed to sub-optimal habitat in Chain Lakes reservoir.

INTRODUCTION

Most temperate water fishes exhibit annual reproductive cycles (Nikolski 1963) which are reflected by seasonal changes in the structure and weight of the gonads (Hoar 1969). Gonad development in fishes has been studied for at least a century (Yamazaki 1965), but catostomids have been largely neglected. Willsrud (1966) examined the tahoe sucker, *Catostomus tahoensis,* and was first to describe monthly increases in oocyte diameter. Later, Andreasen and Barnes (1975) studied the histology of the testes in Utah suckers, *C. ardens,* and bluehead suckers, *C. discobolus*. They also reported gonad indices and oocyte measurements of both species, but they were unsuccessful in preparing tissue sections of the ovaries.

White suckers, *C. commersoni,* and longnose suckers, *C. catostomus,* have been the subjects of several ecological studies, but little is known about their reproductive cycles. Only Lalancette (1975) has documented seasonal changes in the histology and weight of the gonads of white suckers. Comparable information on longnose suckers is lacking. Most other studies on white and longnose suckers have been limited to gross examination of the gonads during spawning. These studies provided information on gonad indices, fecundity, and egg size (Bailey 1969; Bond 1972; Harris 1962; Hayes 1956; Raney and Webster 1942; Stewart 1926).

This chapter reports on histological changes in the ovaries and the testes of white and longnose suckers over a one year period. Gonadosomatic indices and fecundity data are also presented for both species.

STUDY AREA

The study area is approximately 90 km south of Calgary in the east slope of the Rocky Mountains of Alberta. Field studies were carried out at Chain Lakes Reservoir (lat. 50° 11' 47" N, long. 114° 12' 46" W) and Willow Creek, the major inlet stream to the impoundment. The reservoir is long (10 km) and narrow (<1 km) with a surface area of 389 ha. Maximum depth is 9.0 m and mean depth is 5.3 m. Mid summer temperatures exceed 16°C on bottom. The creek and reservoir are ice covered each year from about November to April.

MATERIALS AND METHODS

Field studies were carried out from March 1976, to January 1977. Fish were collected from Willow Creek in May and June, and from Chain Lakes reservoir in March, May-August, November, and January. Suckers were collected from the creek in a two-way fish trap and with a backpack electroshocker. Gillnets of variable mesh sizes (2.54 cm-11.34 cm) were used to collect fish in the reservoir. Suckers were generally captured from the reservoir over a one or two day period during the first week of each month.

All fish were sampled in a routine manner. Sex, maturity, length, and weight were recorded. A scale sample and one pectoral fin were taken for age determination. Gonads were excised and weighed to the nearest 0.1 g. Gonads taken for determination of fecundity and for histological preparation were fixed in Bouin's solution.

Histological sections were prepared from the gonads of 204 white suckers and 90 longnose suckers. A portion of tissue from the anterior region of each gonad was wax imbedded and cross sectioned. Tissue sections (7 μ thick) were mounted on glass microscope slides and stained with iron heamotoxylin and eosin. Microscopic interpretation of tissue sections was aided by reference to Ashan (1966), Lalancette (1975), Turner (1919), and Yamazaki (1965).

The gonadosomatic index (GSI = gonad weight/body weight x 100) was calculated from wet weights obtained in the field. Fecundity was determined from subsamples of ovaries using the dry weight gravimetric method of Healey and Nicol (1975). Mean egg size was determined by measuring a random sample of 10 eggs from each ripe ovary. Simple correlation analyses and Model II regression equations (Sokal and Rohlf 1969) were used to describe relationships between egg number versus length and egg number versus weight. All analyses were confined to adult fish five years and older.

RESULTS

The annual reproductive cycles of white and longnose suckers were reflected by seasonal changes in the weight and histological structure of the gonads. In general, the gonads of both species were comparable with regard to external appearance and rate of gametogenesis. There were, however, some subtle histological differences in the testes of white and longnose suckers.

Ovarian Development

Ovaries of white and longnose suckers are paired cyto-varian organs composed of numerous ovigerous folds in which oocytes develop. The ovaries of both species were similar in external and histological appearance. Changes in the weights of ovaries throughout the year were also comparable between both species. This seasonal variation in ovary weight, illustrated by the gonadosomatic index (Fig. 1), was indicative of certain phases in the annual reproductive cycle. A high GSI in May coincided with the beginning of the spawning season, and as females expended ripe eggs the GSI declined. Ovarian recrudescense was apparent in late summer, and most ovaries had obtained

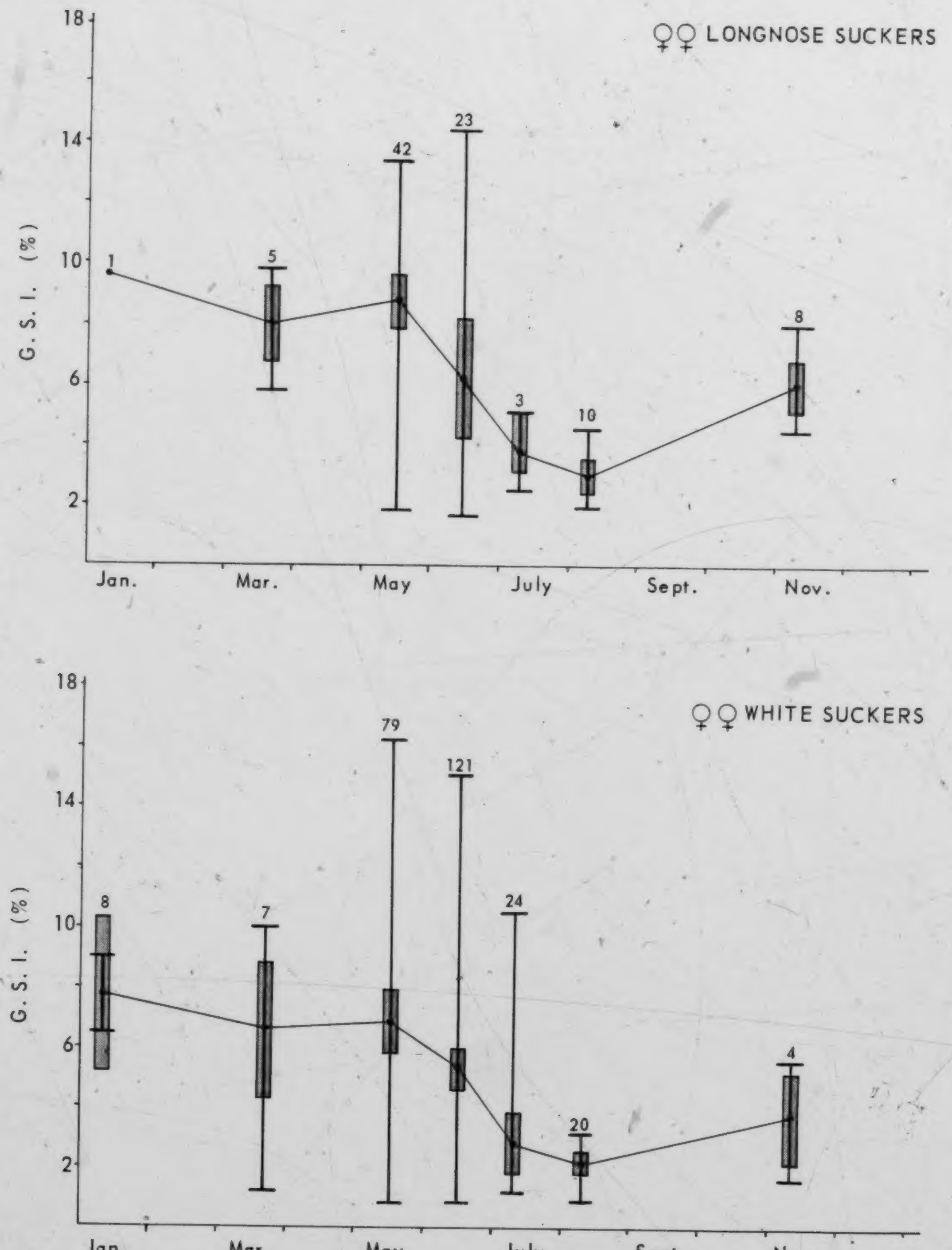


Figure 1. The gonadosomatic index (GSI) of female white and longnose suckers. Points indicate the mean; boxes represent 95% confidence limits; vertical lines show range, and sample sizes are presented above vertical lines.

the bulk of their weight by mid winter. Seasonal variation in ovary weight occurred with concomitant change in cytological structure.

Just prior to spawning the ovaries were filled with large yellow eggs averaging 1.8 mm in diameter. These ripe eggs were visible through the very thin (17-87 μ) wall of the ovary. After spawning the ovaries were red in color and the ovary wall measured 61-247 μ. From this point on, as gonad development proceeded, the ovary wall decreased in thickness and a progression of various oocytes appeared. Oogenesis (including vitellogenesis) was divided into stages based on the appearance of different groups of oocytes throughout the year (Fig. 2). These stages are as follows:

Quiescent Ovaries - Peri-nucleolar oocytes in various stages of transformation were present in the ovary throughout the year. These oocytes were most obvious in July (Fig. 2) and are referred to as recruitment stock (Vladykov 1959). Spherical, early peri-nucleolar oocytes (8-30 μ) had heavily stained nucleoli within a central nucleus that was enclosed by cytoplasm (Plate 1.2). Lalancette (1975) referred to these oocytes as primordial germ cells. Late peri-nucleolar oocytes ranged in size from

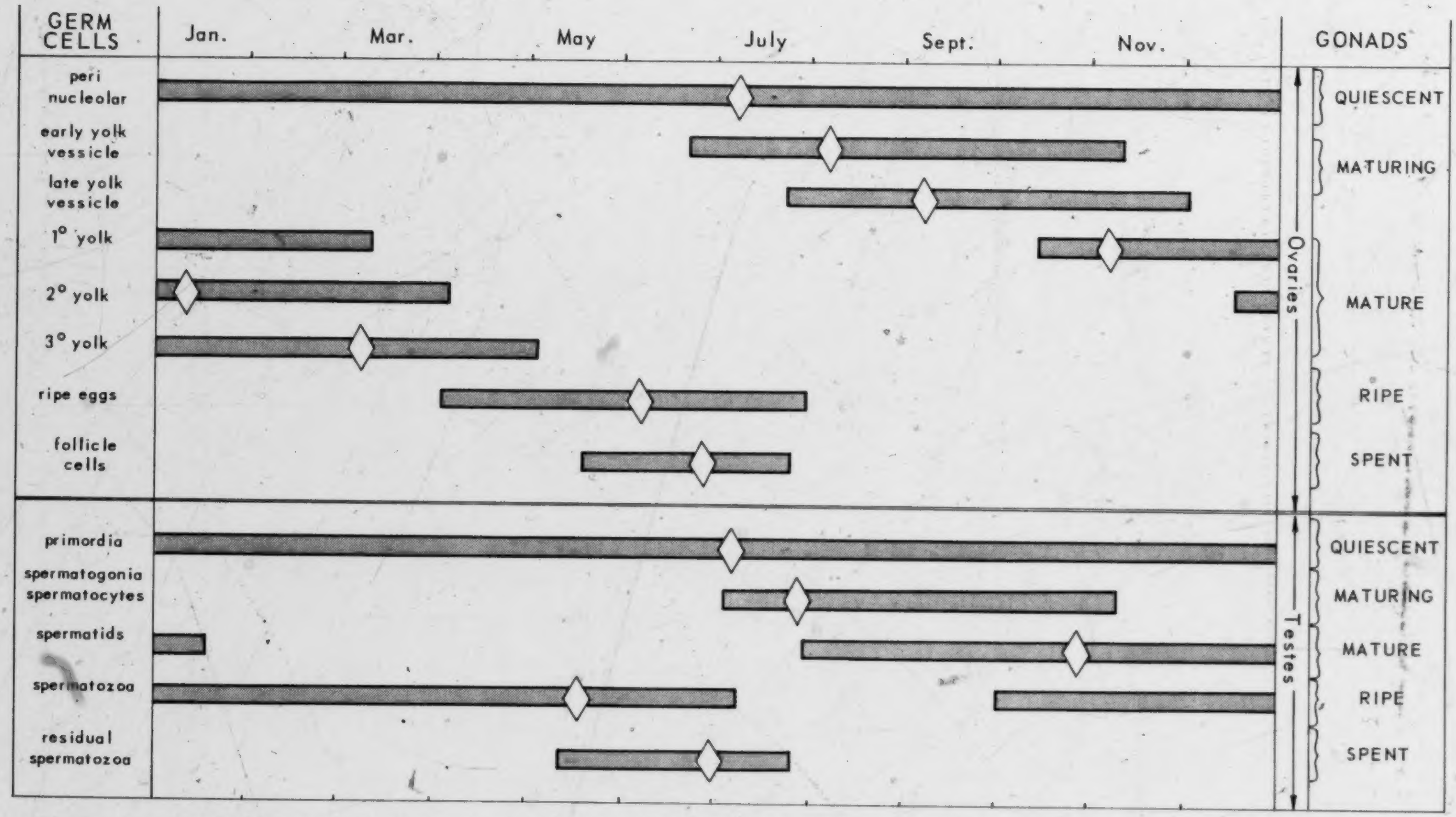
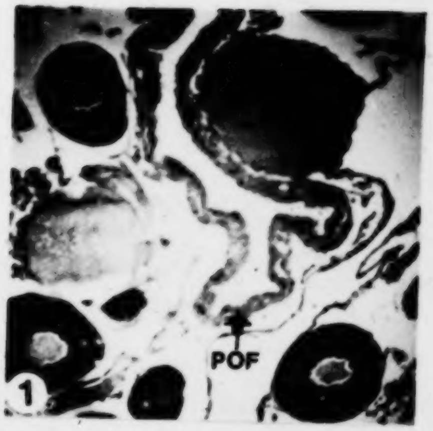


Figure 2. Seasonal gonad development of white and longnose suckers based on the presence of different germ cells in the testes and ovaries. Horizontal bars represent the period of time germ cells are present in the gonads. Diamonds indicate the time of the year when particular germ cells are prominent in the gonads.

Plate 1. Histological sections of sucker ovaries at various stages of maturity depicted by different oocytes - white sucker = WS, longnose sucker = LNS (magnification x 100). (1) Spent WS - post ovulatory follicle, (2) Quiescent WS - perinucleolar oocytes, (3) Maturing WS - yolk vessicle oocyte, (4) Mature WS - secondary (2^{o}) yolk stage oocytes, (5) Mature LNS - tertiary (3^{o}) yolk stage oocyte, (6) Ripe WS - ripe egg. Legend: NL = nucleoli; NU = nucleus; POF = post ovulatory follicle; YG = yolk globules; YV = yolk vessicles; ZR = zona radiata.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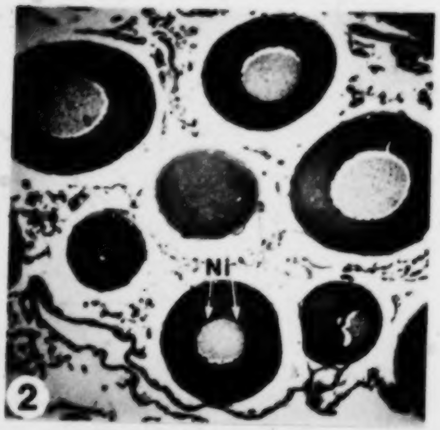
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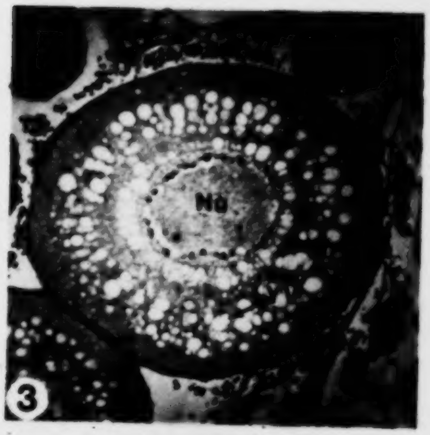
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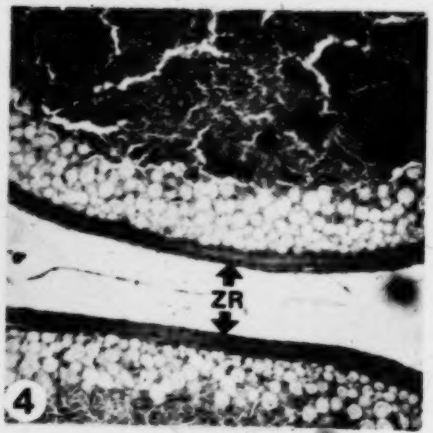
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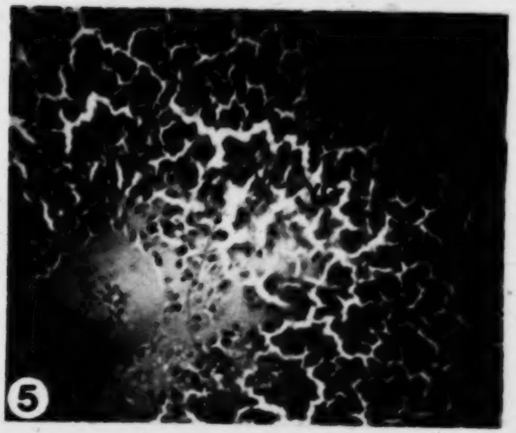
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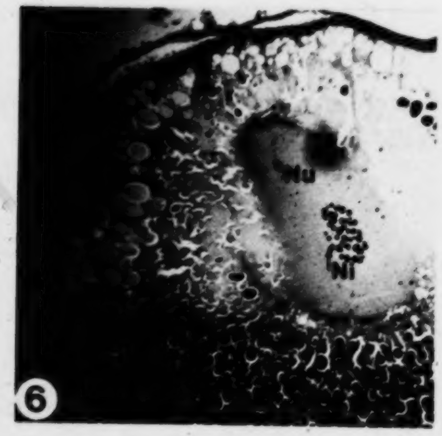
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30-115 μ, and larger oocytes changed from spherical to crescent shaped. At this stage cytoplasm and nucleoli were heavily stained. Numerous (>5) nucleoli were situated at the periphery of the nucleus, hence the term "peri-nucleolar" oocytes. Late peri-nucleolar oocytes were characterized by the appearance of the secondary yolk nucleus near the outer edge of the primary nucleus. This structure is referred to as the secondary nucleus of Balbiani (Lalancette 1975).

Maturing Ovaries - Large, spherical yolk vessicle oocytes appeared and increased in number from July to November (Fig. 2). In the early stages, oocytes were 145-275 μ in diameter, and the secondary nucleus of Balbiani was located just inside the enlarged zona radiata (egg wall). As oocytes increased in size (290-385 μ) round yolk vessicles appeared near the periphery of the cytoplasm (Plate 1.3). In the latter stages, yolk vessicles encroached upon the nucleus and occupied most of the cross sectional area of each oocyte. Peripheral nucleoli, still heavily stained, were visible around the yolk nucleus. These oocytes measured 350-600 μ.

Mature Ovaries - Oocytes at the yolk globule stage appeared from November to March (Fig. 2), and females with ovaries containing these oocytes would spawn the following spring. The appearance and proliferation of yolk globules in yolk stage oocytes resulted in a major increase in size. Primary stage oocytes ranged in size from 850-1010 μ, and yolk globules enveloped the nucleus. As the oocytes enlarged (1080-1430 μ) during the secondary stage, yolk globules occupied at least 50% of the cross sectional area of the individual oocytes. As yolk globules occupied more space, yolk vessicles were pushed to the periphery of the oocytes. During this phase individual yolk vessicles were also decreasing in size. At the tertiary stage, oocytes were 1270-1580 μ and yolk vessicles formed only a narrow band around the central mass of yolk globules (Plate 1.4, 1.5). Nucleoli, once peripheral, lost their affinity for stain and migrated to the centre of the yolk nucleus.

Ripe Ovaries - Oocytes reached their largest size (1.8 mm) from January to May (Fig. 2). Yolk globules occupied over 80% of the cross sectional area in individual oocytes and the band of yolk vessicles became thinner. At this stage the zona radiata was 10 μ thick. Sometime prior to ovulation the nucleus migrated to the animal pole (Plate 1.6) (micropyle), and oocytes changed appearance from opaque to translucent. The nucleus was seldom observed immediately adjacent to the zona radiata probably because it took this position just before ripe eggs were released from the ovary, and totally ripe females were rare in the sample. At this stage, ovulated eggs could be expelled from the female with slight pressure to the abdomen.

Spent Ovaries - Ovaries in this condition were obtained in May, June, and early July (Fig. 2). Flacid ovaries contained numerous post ovulatory follicles and some unspent eggs. Follicle cells that once surrounded the ripe egg formed irregular shaped sacs throughout the ovary (Plate 1.1).

Testicular Development

Testes of white and longnose suckers are paired, elongate, and highly convoluted. Each coil of the testis forms a lobule which is comprised of a network of seminiferous tubules containing various germ cells. Testes of both species exhibited similar seasonal changes in weight as illustrated by the GSI (Fig. 3). The GSI was lowest in June and July following spawning. Unlike the ovaries, testes gained virtually all their weight by late summer. In August, testes weighed at least as much as they would

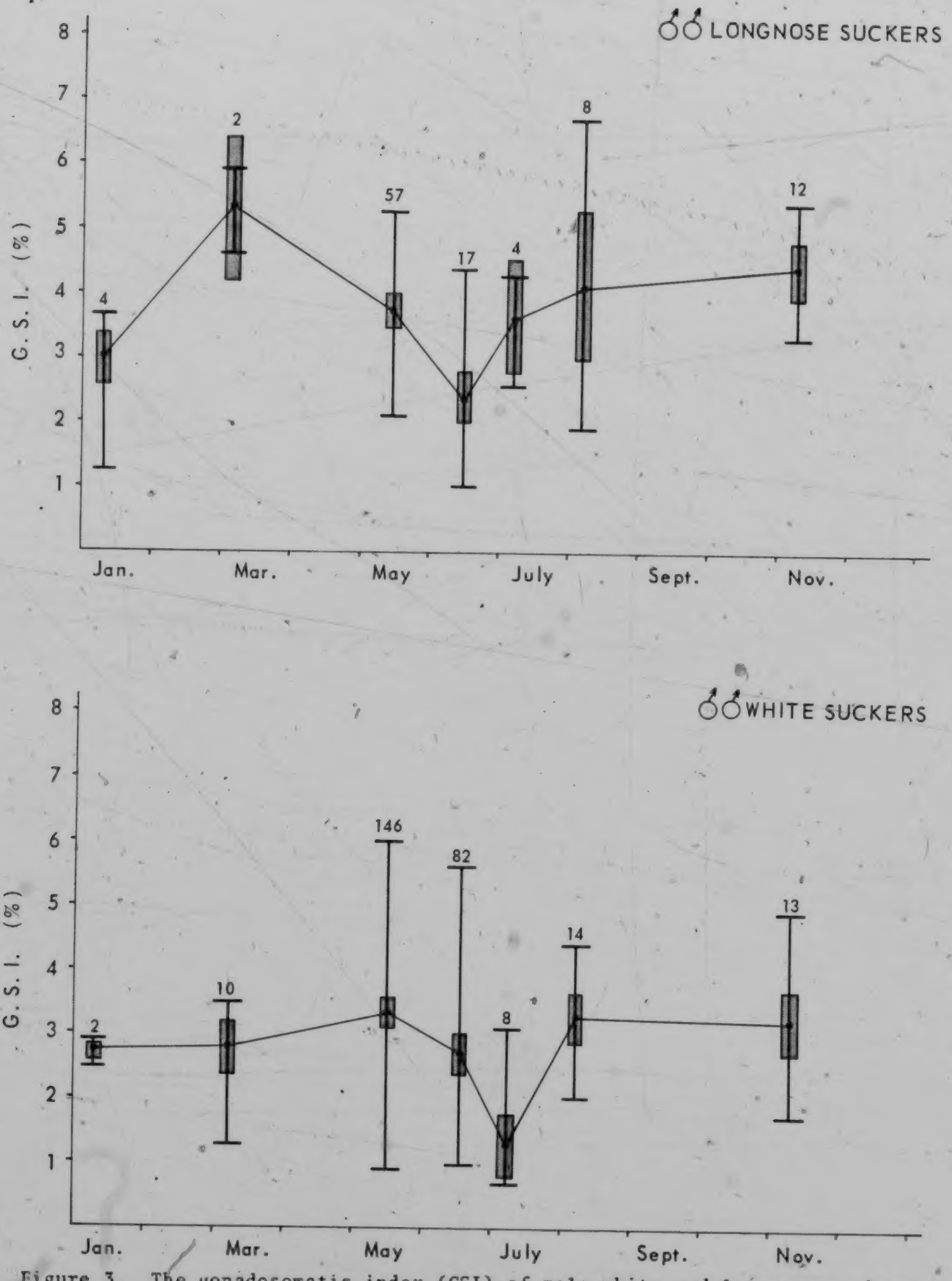


Figure 3. The gonadosomatic index (GSI) of male white and longnose suckers. Points indicate the mean; boxes represent 95% confidence limits; vertical lines show range; and sample sizes are presented above vertical lines.

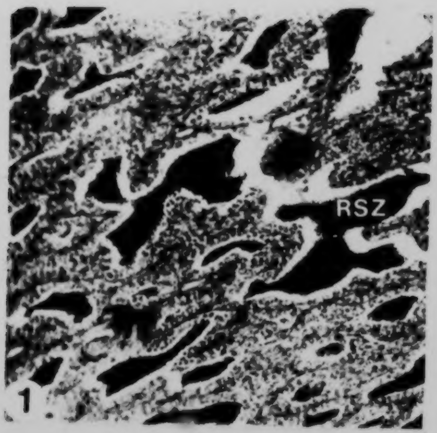
during the spawning period. Advanced sexual maturity was apparent by November when spermatozoa filled the testes and nuptual tubercles appeared on the fins. The unusually high GSI for longnose suckers in March was likely a result of a small sample of exceptionally large males.

The testes of white and longnose suckers were similar externally but there were some differences in the rate of gametogenesis and histological appearance. Longnose suckers appeared to mature earlier in the summer than white suckers. Spermatids appeared in the testes of longnose suckers as early as July, but not until August in white suckers. Probably the greatest difference in the testes was the dissimilar shape of the spermatozoa. The heads of spermatozoa in longnose suckers were spherical while those in white suckers were oval.

Histologically, testes did not undergo seasonal changes of the magnitude seen in the ovaries. The dimensions of male germ cells varied only a few microns during the year. Different phases of spermatogenesis were determined by the appearance and juxtaposition of germ cells in the seminiferous tubules. During spermatogenesis there were also changes in the diameter of the seminiferous tubules and in the thickness of the septa (fiberous tissue between tubules) and the tunica albuginea (testes wall). During spawning, tubules reached their maximum diameter (100-300 μ) and were filled with spermatozoa. Shrunken tubules in the spent and quiescent testes expanded through the year as they began filling with spermatozoa. The tunica albugenia and septa decreased in thickness as the testes matured. The tunica albuginea was 26-80 μ after spawning and only 9-12 μ just prior to spawning. Spermatogenesis was divided into stages based on the appearance of different groups of sperm cells (Fig. 2). These stages are as follows:

Quiescent Testes - Testes at this stage were obtained in July (Fig. 2). Primary germ cells were most obvious at this stage although they were located near the tubular septa throughout the year. By July most residual spermatozoa had disappeared apparently as a result of phagocytosis (Andreasen and Barnes 1975). Primary germ cells in various stages of mitosis had deeply stained chromatin material. The nucleus in each cell was centrally located in the cytoplasm, and the cells measured 6-20 microns. Primary germ cells were clustered in groups that formed a ring around the inside of each tubule (Plate 2.2).

Plate 2. Histological sections of sucker testes at various stages of maturity - white sucker = WS; longnose sucker = LNS. (1) Spent WS (100x), (2) Quiescent WS (100x), (3) Maturing WS (400x), (4) Mature WS (400x), (5) Ripe WS showing spermatozoa (1000x), (6) Ripe LNS showing spermatozoa (1000x). Legend: PGC = clusters of primary germ cells; RSZ = residual spermatozoa; SG = spermatogonia; ST = spermatids; SY = spermatocytes; SZ = spermatozoa.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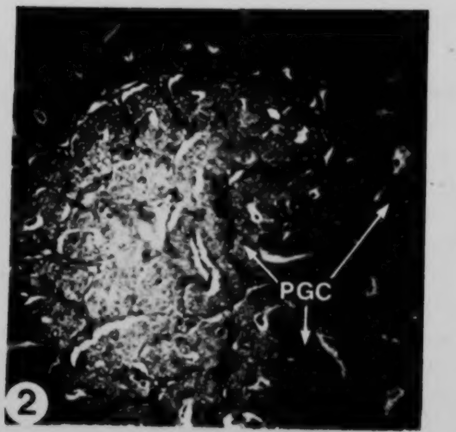
RSZ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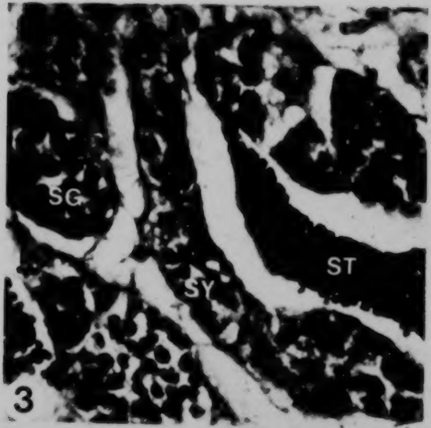
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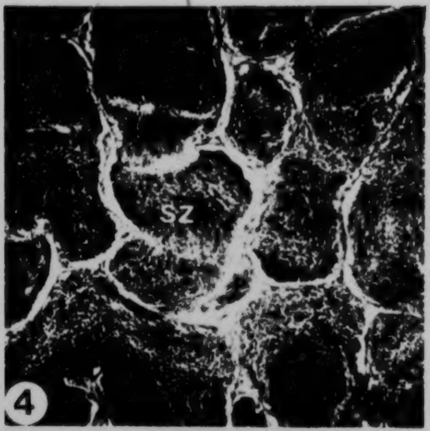
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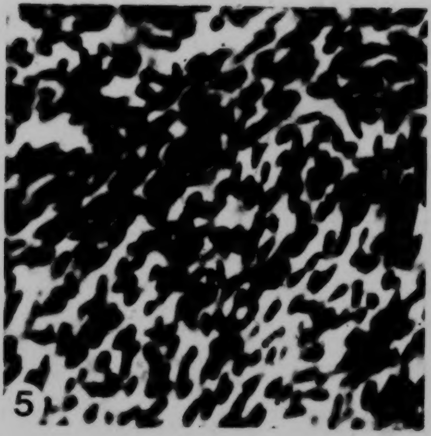
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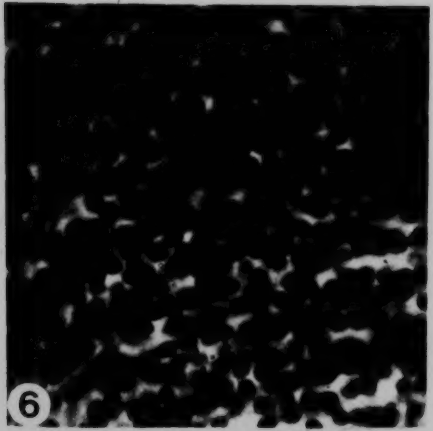
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Maturing Testes - In maturing testes, spermatogonia and spermatocytes appeared in early August (Fig. 2). Longnose suckers appeared to reach this condition slightly before white suckers. Spermatogonia were 10-17 μ and clustered in groups of 30-100 cells per cluster. These clusters filled the tubules, and as the spermatogonia transformed into spermatocytes the cells were no longer arranged in closely packed groups. During this stage the tubules ranged from 70-150 μ in diameter. Tubules contained spermatids in the later stages of the maturing testes (Plate 2.3).

Mature Testes - By November testes were packed with spermatids and spermatozoa: spermatocytes were not observed (Fig. 2). Spermatids of both species were spherical and measured less than 2 μ. Spermatids were normally located near the periphery of the tubules surrounding the spermatozoa. Spermatozoa were far more numerous than spermatids at this stage (Plate 2.4). Tubules were 15-160 μ in diameter in the mature testes.

Ripe Testes - There was a marked reduction in the number of spermatids from November to January, and by March no spermatids were observed (Fig. 2). There was little difference in the appearance of the testes from March to

May, all lobules were packed with spermatozoa. The spermatozoa of white suckers were oval and 3.6 μ long and 1.5 μ wide (Plate 2.5). The spermatozoa of longnose suckers were spherical and 2.4 μ in diameter (Plate 2.6). Tubules in the ripe testes ranged from 100-280 μ in diameter.

Spent Testes - Testes in this condition were obtained primarily in June and July (Fig. 2). Unspent spermatozoa occupied the inner most portion of the tubules (Plate 2.1). Primary germ cells bordered the periphery of the tubules which measured 40-270 μ.

Fecundity

The number of ripe eggs in 39 female white suckers ranged from 9,731 to 36,737 with a mean fecundity of 15,127. The length-relative fecundity was 441.0 egg/cm fork length and the weight-relative fecundity was 29.8 eggs/g body weight. The fecundity of 31 longnose suckers ranged from 11,369 to 21,710 with a mean egg number of 16,485. The length relative fecundity was 469.7 eggs/cm fork length and the weight-relative fecundity was 32.9 eggs/g body weight.

There was a trend for increasing fecundity with age for both species (Table 1). Length and weight were highly correlated with egg number: weight more so than length (Table 2). Length, weight, and fecundity data were log transformed prior to regression analyses. Fecundity-length and fecundity-weight regression formulae for both species show an increase in egg number with size (Table 2).

Mean egg diameter for white suckers was 1.78 mm±0.3 (N=39) and 1.79 mm±0.2 (N=31) for longnose suckers. There was a low positive correlation ($r=.39$, $p<0.05$) between egg diameter and fecundity in white suckers but no correlation ($r=.01$, $p>0.05$) in longnose suckers.

Table 1. Number of eggs in white and longnose sucker in relation to age.

WHITE SUCKER

AGE	N	$\bar{x}$ EGG NO. ±(SE)	RANGE
V	5	12,600±1,082	9,731-15,490
VI	18	12,558± 674	8.920-17,550
VII	8	12,740± 884	8,889-16,307
VIII	5	19,364±2,053	12,739-24,216
IX	2	36,461± 321	36,095-36,737
XII	1	23,420	- -

$\bar{x}$ Egg No. = 15,127 $\bar{x}$ Fork Length = 343 mm
$\bar{x}$ Weight = 508 g

LONGNOSE SUCKER

AGE	N	$\bar{x}$ EGG NO. ±(SE)	RANGE
V	4	15,403±3,106	11,369-24,670
VI	18	16,256± 697	12,599-21,401
VII	7	16,467±1,393	11,368-20,917
VIII	2	20,784± 926	19,858-21,710

$\bar{x}$ Egg No. = 16,485 $\bar{x}$ Fork Length = 351 mm
$\bar{x}$ Weight = 501 g

Table 2. Regression formulae for log fecundity-log fork length (mm) and log fecundity-log body weight (g) for white and longnose suckers. All correlation coefficients (r) significant, $p<0.05$.

WHITE SUCKERS

$\log \text{fecundity} = 2.82\ (\log \text{fork length}) - 3.0$
$r = .72$

$\log \text{fecundity} = 1.09\ (\log \text{body weight}) + 1.2$
$r = .89$

LONGNOSE SUCKERS

$\log \text{fecundity} = 2.64\ (\log \text{fork length}) - 2.5$
$r = .58$

$\log \text{fecundity} = 0.93\ (\log \text{body weight}) + 1.69$
$r = .69$

DISCUSSION

Annual reproductive cycles of temperate water fishes are timed to provide offspring with the best conditions for survival and development (Hoar 1969). White and longnose suckers have reproductive cycles that are geared to spring spawning. Although gametogenesis is continuous throughout the year, much of the gonad development occurs in the summer and fall, especially in the testes. This trend is also apparent in Utah and bluehead suckers (Andreasen and Barnes 1975). In general, testicular development in catostomids proceeds rapidly during the late summer. Rapid spermatogenesis in the fall results in major increases in testicular weight and proliferation of spermatozoa in October and November. Male suckers overwinter with some spermatids and many spermatozoa in the testes.

As in my study, Andreasen and Barnes (1975) report that oogenesis lags behind spermatogenesis. Lalancette (1975) also noted this phenomenon in white suckers. Generally, in catostomids, oogenesis begins in midsummer but major increases in ovary weight are not apparent until after August. Oogenesis proceeds rapidly through the fall as ovaries increase in weight. After January, as yolky material accumulates in the oocytes, ovarian development proceeds slowly up to spawning time. Increments in oocyte diameter also reflect the gradual rate of ovarian development during the winter. This was documented in Utah and bluehead suckers (Andreasen and Barnes 1975) and in the Tahoe sucker (Willsrud 1966).

Lalancette (1975) noted that variations in the maturity index (i.e., GSI) were related to histological changes in the gonads of white suckers. The GSI of white and longnose suckers in the present study also coincided with different stages of gametogenesis. Major increases in the GSI were indicative of rapid spermatogenesis and oogenesis. Likewise, decreases in the GSI were associated with gonads in post spawning condition.

Teleost reproductive cycles fall into two main categories (Nikolski 1963). The first category is typical of cyprinids where the early stages of gametogenesis are completed in the fall. During the winter very little development takes place until final ripening occurs 10-15 days before spawning in the spring. The second pattern is typical of percoid fishes where spermatogenesis occurs rapidly in the fall and oogenesis lags behind as eggs develop gradually over the winter. The gonad cycles in perch, *Perca fluviatilis, Perca flavescens,* (Turner 1919, Le Cren 1951), lake chub, *Couesius plumbeus* (Ashan 1966), and minnows *Phoxinus laevis* (Bullough 1939) appear to conform with Nikolski's (1963) two categories.

Catostomids are more closely related to cyprinids than to percoids, but the reproductive cycles in suckers are more similar to the type found in the latter group. Andreasen and Barnes (1975) point out that the testicular cycle in Utah and bluehead suckers is similar to testicular development in percoids but ovarian development is intermediate between the patterns seen in percoids and cyprinids. They documented a gradual increase in oocyte diameter and gonad weight through the winter but found no prespawning increases in weight or egg size that are typical of perch ovaries. On the other hand, Lalancette (1975) found that the maturity index in white suckers remained fairly stable from December to April but that it increased prior to spawning in May. White and longnose suckers in the present study showed gradual increases in ovary weight from January to May but there was no major prespawning inclination in the GSI. Although catostomids exhibit some variability in the pattern of ovarian development the stages of oogenesis and the increases in ovary weight are comparable to those found in percoids.

There were no differences in the histological appearance between the ovaries of white and longnose suckers. Oogenesis proceeded at about the same rate in both species and this was reflected by coincident GSI values. The general pattern of testicular development was comparable in both species, but longnose suckers matured earlier in the year than white suckers. Advanced sexual maturity was marked by the proliferation of spermatids in longnose testes in early August. The GSI for longnose suckers also began climbing before an increase was detected in the GSI of white suckers. The major histological difference between white and longnose sucker testes was in the gross morphology of the spermatozoa. Although spermatozoa differed in appearance, gametes must be interspecifically compatible because hybridization has been reported between white and longnose suckers (Nelson 1973). It is not known if spermatozoa from both species are equally capable of cross fertilization.

Fecundity is defined by Bagenal and Braum (1978) as:

> "the number of ripening eggs in the female prior to the next spawning period"

This definition was adopted in the present study. An average fecundity of 15,127 in white suckers from Willow Creek and Chain Lakes was lower than the fecundities in other populations. These fecundities range from a relatively low value of 19,215 (Hayes 1956) to over 34,000 (Bond 1972). Scott and Crossman (1973) consider the usual egg number to be 20,000-50,000. Length-relative fecundity (441 eggs/cm fork length) and weight-relative fecundity (29.8 eggs/g body weight) were also low in comparison to the values given by Bond (1972) of 915.2 eggs/cm fork length and 45.6 eggs/g body weight.

Longnose suckers from Willow Creek and Chain Lakes had a lower fecundity (16,485) than most other populations. Scott and Crossman (1973) report that the egg number of the species ranges from 17,000-60,000 per female. Hayes (1956) found two individual longnose suckers to have an average fecundity of 11,325. Length-relative fecundity (469.7 eggs/cm fork length) was also lower than the median value reported by Bailey (1969) of 622.5 eggs/cm fork length.

Within a species, low fecundity may be caused by sub optimum temperature, poor nutrition, or crowding (Blaxter 1959). White and longnose suckers in the Willow Creek-Chain Lakes system had relatively low fecundities. One cause of this low egg production could be poor nutrition.

Low fecundity may also be a result of crowding. In the time since Chain Lakes reservoir was constructed the sucker population has burgeoned. If the reservoir is overpopulated with suckers low fecundity may be a means of population control. Everhart *et al*. (1975) point out that, among other things, decreased fecundity serves to prevent population explosion. Further study of the sucker population in the reservoir and on the productivity of the impoundment are needed to test these hypotheses.

Interspecific differences in egg size and fecundity are related to spawning strategy. Species that broadcast their gametes in open water (gadids, clupeids) have relatively high fecundities; whereas, species that provide some protection for their spawn (salmonids, gasterosteids) have relatively low fecundities (Blaxter 1969). There is also a trend for fecundity to be inversely related to egg size (Blaxter 1969).

Catostomids are relatively fecund as compared to, for example, salmonids (Scott and Crossman 1973), and this is related to their respective spawning strategies. Suckers broadcast their eggs near the substrate without any nest preparation. Salmonids, on the other hand, deposit their eggs in redds (nests). Suckers do not protect their spawn, therefore; because egg mortality is high, they must have high fecundities. Although fecundity and egg mortality are high in species like suckers the percentage of egg mortality may be comparable to less fecund species (Everhart *et al*. 1975). High fecundity and egg size in suckers are related. Ripe eggs from white and longnose suckers are small (1.8 mm) relative to the larger eggs (4-5 mm) of salmon and trout (Scott and Crossman 1973).

Fecundity of white and longnose suckers was positively correlated with length, and weight, and age. In most species the larger and older fish generally produce the greater number of eggs (Nikolski 1963). In the past, fecundities of white and longnose suckers have been obtained from relatively few fish, hence it is difficult to see relationships between age, size, and fecundity. Fecundity data from a few studies indicate that egg number is higher in larger suckers (Bailey 1969; Bond 1972; Raney and Webster 1942; Stewart 1926). Bond (1972) found that egg size was inversely related to fecundity but this association was not apparent in white and longnose suckers in the Willow Creek-Chain Lakes system.

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GENERAL DISCUSSION

Teleost reproductive cycles are controlled by certain exogenous and endogenous variables. Exogenous factors, photoperiod and temperature, regulate endogenous endocrine systems and gonad development (De Vlaming 1972). Cyclical environmental changes are related to gonad maturation and the subsequent events of migration and spawning (Hoar 1953). Harden-Jones (1968) proposed that reproduction and migration are dependent upon priming and releasing mechanisms. Priming mechanisms, photoperiod and temperature, ready fish for migration; at spawning time, releasing mechanisms induce movement of reproductively mature individuals. Temperature, stream flow, and light are releasing mechanisms implicated in the spawning migrations of white and longnose suckers.

White and longnose suckers typically spawn in tributaries of larger bodies of water during the spring when stream temperature and discharge begin to increase. The effects of temperature and discharge cannot be totally divorced, but the findings of this study indicate that temperature initiates movement whereafter discharge regulates movement, to some extent. In contrast to these findings, Geen (1958), and Geen *et al*. (1966), and others surmise that variation in daily temperature is the most important factor governing upstream movement of white and longnose suckers.

Fish migration is undoubtedly controlled by a synergism of many factors, hence it is dangerous to assume that one or two environmental factors are solely responsible for governing movement. Nonetheless, the relationship between discharge and migration cannot be ignored.

It seems plausible that increasing discharge from a stream into a lake would attract migrant fish to the mouth of the stream. Rising temperature may initiate upstream movement, but without high discharge to broadcast warmer water into a lake relatively few fish would be attracted to tributary streams. A threshold temperature (10°C for white and longnose suckers at Willow Creek) must be reached to initiate upstream movement. Upstream migration may be contingent upon warming waters as Brett *et al*. (1958) found that salmon swim more rapidly at higher temperatures. Although temperature is an important prerequisite to migration, discharge is still an important regulator of upstream movement. Reviewing the literature on upstream movement of salmonids, both spring and fall spawning species, Banks (1969) concluded that spawning migrations are associated with increased water flow. However, he acknowledged the possible importance of related variables by saying,

> ". . . factors like water and air temperature, turbidity, atmospheric pressure, cloud cover, pH and variations in the concentration of many dissolved ions are associated with the rate of water discharge in a more or less direct fashion"

Light also has a direct bearing on upstream and downstream movement of white and longnose suckers. Virtually all instream movement occurs at night. Nocturnal movement of salmonids is considered an "anti predator device" (Banks 1969). Night activity in suckers probably reduces predation and this is an important adaptation for lower trophic organisms. Suckers are also night active in lentic waters (Spoor and Schloemer 1938; Hayes 1956), and nocturnal inshore movements may help fish locate spawning streams.

White and longnose suckers exhibit homing behavior by returning to the same spawning stream in successive years (Geen *et al*. 1966). Olson and Scidmore (1963) report that white suckers have an affinity to a particular spawning site, and that repeat spawners return to given streams from all parts of a lake. The first individuals to reach a stream generally ascend farther and remain in the stream longer than later migrants. The maximum distances moved by white suckers and longnose suckers tagged and recaptured during May 1976 at Willow Creek were 10.3 km and 1.1 km respectively. Although some suckers migrated considerable distances upstream most were recaptured in the lower 3.0 km of the creek. Over the summer, fish tagged in the lower reaches were not recaptured in the upper reaches. This does not imply that suckers are incapable of migrating over long distances; rather, suckers probably do not move upstream to a large degree after spawning is finished.

White and longnose suckers generally spawn after major spring freshets. The incubation period of both species is approximately two weeks at normal spring water temperatures of 10-12°C. Yolk sac larvae remain in the gravel for about 11 days after hatching. It is not known why larvae do not emerge from the substrate immediately after hatching. Sucker larvae may react to light as salmonid larvae do. Yolk sac salmonid larvae are photonegative; however, after the yolk sac is absorbed larvae become photopositive and emerge from the gravel (McPhail pers. comm. 1979). Upon hatching, suckers remain on bottom and exhibit writhing movements which may be a natural means of burrowing into the gravel. Newly hatched sucker larvae are feeble, and because they possess large yolk sacs they are incapable of swimming. Sucker larvae emerge from the gravel with shrunken yolk sacs and relatively large pectoral fins. At this time (27 days from fertilization) larvae are about 12 mm long. Having made the transition from yolk sac larvae to the fry stage, suckers begin their descent to nursery areas.

Sucker fry drift mainly at night. Nocturnal movement of fry, as in adult suckers, probably reduces predation (Gale and Mohr 1978). The evolution of nocturnal movement as a result of selective pressure from predation is purely speculation. Other environmental factors independent of predation may cause night movement. Northcote (1962) suggests that nocturnal movement of rainbow trout, *Salmo gairdneri,* results from a loss of contact with the substrate. He proposes that trout fry undergo a period of partial night blindness while the eye becomes dark adapted. Partial night blindness and subsequent loss of orientation to the bottom may explain nocturnal drift of sucker fry.

Sucker fry move downstream near surface. This phenomenon may be related to an increase in buoyancy caused by initial inflation of the swim bladder. Long and Ballard (1976) noted that the swim bladder may inflate in 15 mm long sucker fry about 14 days post hatch. Although these fry were slightly larger than those captured in drift nets at Willow Creek, the swim bladder may be semi-functional in 12 mm long fry. Alternatively, sucker fry may actively move to the surface to "gulp" air in order to inflate the swim bladder. The swim bladders in physostomus fish, suckers included, can be inflated by atmospheric gas (Nikolski 1963).

Coincident with initial inflation of the swim bladder is the rhythmic movement of the jaws (Long and Ballard 1976). According to Stewart (1926), sucker fry begin feeding on external food when they reach 12 mm in length. Fry, 12-16 mm long, feed near surface and Stewart (1926) terms this the "top feeding stage." It appears that certain environmental and anatomical conditions are related to the predominance of sucker fry in the upper water column.

Suckers generally spend their juvenile years in lentic waters and return to streams, as adults, to spawn. Lakes and reservoirs provide good rearing and overwintering habitat. Sucker fry feed initially on zooplankton, usually abundant in lakes, and soon make the transition to benthos (Crawford 1923; Hubbs and Creaser 1924; Siefert 1972). Food, among other things, is an important factor in determining growth rate. White suckers in the Willow Creek-Chain Lakes system are relatively slow growing. Although a slow growth rate may be genetically inherent, environmental constraints such as inadequate food may impair growth. The underlying reasons for slow growth are complex; factors involved include: low temperature, over crowding, competition, lack of predation, and pollution. Several of these factors may act in consort to provide a mechanism for regulating growth. Unexpectedly, longnose suckers in the Willow Creek-Chain Lakes system have a growth rate comparable to other populations. Once again, genetic control of growth cannot be ruled out, but certain environmental factors should be considered. Longnose suckers are far outnumbered by white suckers both in Willow Creek and in Chain Lakes. Presumably, longnose suckers do not suffer from severe intraspecific competition for food. In addition, longnose suckers may not be competing with white suckers for food: differences in preferred temperature may provide spatial separation of feeding habitats. If interspecific and intraspecific competition for food do not pertain to longnose suckers, growth should not be impaired. Conversely, intraspecific competition in white suckers, because they are so numerous, may limit growth. The underyling assumption of this premise is that food is a limiting resource. Since food habits of suckers were not considered in this study, further work is needed in order to make succinct conclusions regarding diet as it relates to growth of white and longnose suckers in Willow Creek and Chain Lakes.

White and longnose suckers in the Willow Creek-Chain Lakes system grow relatively fast until sexual maturity is reached. Relative growth rate declines markedly at the age of V, presumably because more nutrients are being diverted into production of gametes rather than into somatic tissue. In sexually mature suckers of the same age, females are usually larger than males. That females are larger than males is a necessary aspect of their reproductive biology because females must accommodate much larger gonads than males. Ovaries of white and longnose suckers represent a much higher percentage of body weight than do the testes.

Gonad weight of suckers varies seasonally and the annual gonadosomatic index reflects microscopic changes in the ovaries and testes. Suckers, like other temperate freshwater fish, take advantage of the productive open water months to begin proliferation of gametes. This is particularly evident in males as testes are mature by November. Ovaries also gain much of their weight during late summer and fall, but oocytes do not become fully developed until early spring. Histological examination of sucker gonads indicates that gametogenesis is actively in progress during all but about two months of the year.

The adaptive capabilities of white and longnose suckers enables them to inhabit a wide range of habitats. They are highly fecund and prolific species. Although fecundity may be high, so must larval mortality. Unseasonably high or low temperatures increase mortality of white sucker embryos (McCormick *et al.* 1977). Sucker fry also fall prey to piscivores like rainbow trout and mountain whitefish (pers. obs.). If constraints on mortality are relaxed sucker populations may increase. Subsequent overpopulation may lead to reduced growth and lower fedundity. White suckers, more so than longnose suckers, seem to be suffering the effects of overpopulation in the Willow Creek-Chain Lakes system.

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APPENDIX I

Water chemical analyses, Willow Creek, December 1978.

PARAMETER	VALUE
pH	8.1
electrical conductivity	0.35 µmho
Ca + Mg	59 mg/l
Na	7 mg/l
HCO_3	226 mg/l
Cl	<0.3 mg/l
SO_4	14 mg/l
Fe	0.2 mg/l
NO_3-N	<0.1 mg/l
K	1 mg/l
Fe	<0.1 mg/l
TDS	307 mg/l